Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-151

December 1971

DOES THE MOUNTAIN PINE BEETLE CHANGE HOSTS IN MIXED LODGEPOLE AND WHITEBARK PINE STANDS?

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ABSTRACT

*Lodgepole pine (*Pinus contorta *Dougl.) and whitebark pine (*P. albicaulus *Engelm.) losses attributable to the mountain pine beetle (*Dendroctonus ponderosae *Hopkins) were compared in three study areas within two mixed species stands at high elevations. Results suggest that this beetle displays host specificity for the tree species in which it completed larval development because extensive mortality in one host species did not result in comparable mortality in an associated species.*

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) causes serious mortality in many lodgepole pine (*Pinus contorta* Dougl.) forests. This beetle also inflicts mortality in whitebark pine (*P. albicaulis* Engelm.) and limber pine (*P. flexilis* James) (McCambridge and Trostle 1970). Instances where this beetle caused significant mortality to whitebark pine while surrounding lodgepole pine stands remained relatively uninfested were reported by Evenden (1933). Indications that the beetle preferred whitebark and limber pine to lodgepole pine where these species were growing in mixed stands were noted by Evenden and others (1943). The purpose of our study was to determine whether a mountain pine beetle population in lodgepole pine would infest nearby whitebark pine trees and vice versa. The need for answers to these questions is obvious to land managers confronted with beetle infestation situations.

STUDY SITUATIONS

Three study areas containing stands of mixed species were selected to meet the requirements of two situations (see fig. 1). The first situation involved adjoining study areas, which were located near Togwotee Pass on the Teton National Forest. The

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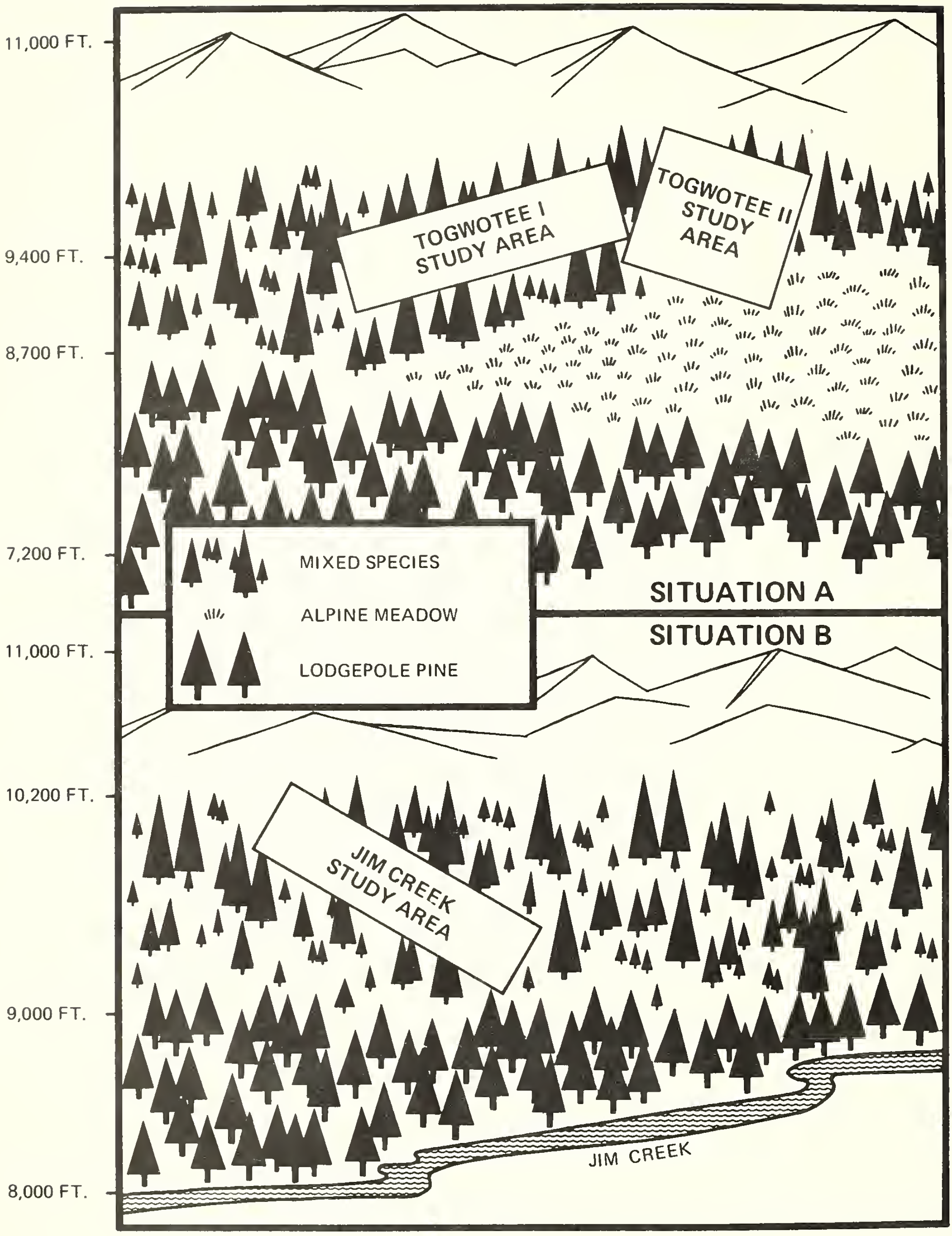

Figure 1.--Sketch depicts the basic field conditions studied.

first study area was called Togwotee I; it was located within elevations ranging from 8,700 to 9,300 feet. The second study area, called Togwotee II, was located within elevations ranging from 8,900 to 9,400 feet. Immediately below Togwotee I was an extensive stand of lodgepole pine that had been infested by the mountain pine beetle over an 8-year period, 1960 to 1968.

Situation 2 involved only one study area, called Jim Creek; it was located on the Bridger National Forest within elevations ranging from 9,000 to 10,200 feet. Unlike the species mixture on the first two study areas, whitebark pine predominated on this study area. Furthermore, the stand had been infested by the mountain pine beetle over a 3-year period, 1961 to 1964. This study area also was located above an extensive stand of lodgepole pine; however, the stand had not been infested by the beetle.

In the three study areas, each of which covered approximately 4 square miles, fixed 1/10-acre plots were established in a grid pattern: 20 in Togwotee I and in Jim Creek; 30 in Togwotee II. We counted all trees 4 inches and larger in diameter at breast height (d.b.h.); the species mixture in the sample is reflected in the following tabulation:

Species	*Togwotee I*	*Togwotee II*	*Jim Creek*
Lodgepole pine	198 (42)[4]	84 (16)	14 (3)
Whitebark pine[5]	111 (23)	160 (31)	321 (75)
Engelmann spruce and subalpine fir	163 (35)	275 (53)	93 (22)

Trees were recorded as follows: (1) alive; (2) killed by mountain pine beetle; (3) killed by other causes, such as tree suppression, other insects, or disease.

Stems that forked at diameters below breast height were recorded separately. A multiple-forked candelabrum-like bole often develops in whitebark pine. All trees counted were categorized into 1 inch d.b.h. classes--4.0 to 4.9 inches, 5.0 to 5.9, etc.

For each of the two species, phloem thicknesses were measured in hundredths of inches. These measurements were taken at d.b.h. on opposite sides of the bole from two living trees in each diameter class on each 1/10-acre plot.

RESULTS AND CONCLUSIONS

Situation 1.--In the Togwotee I study area, the mountain pine beetle killed 15.2 percent of the lodgepole pine trees as compared to 3.6 percent of the whitebark pine trees (fig. 2). Mortality in this study area had been very low prior to 1965, after which the trees in this area were infested by beetles emerging from the lodgepole pine stands below the study area. In these lodgepole pine stands, the mountain pine beetle had killed approximately 25 percent of the trees by 1968 (Amman and Baker, in press). By 1970, the peak of the infestation within the study area had passed.

The large amount of mortality of lodgepole pine (in contrast to that occurring in whitebark pine) indicates that adult beetles from broods maturing in lodgepole pine prefer to infest the same species of pine in which they completed their larval development.

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[4]Figures in parentheses show percent each species is of the total number of trees in each area.

[5]Also includes some limber pine on four Jim Creek plots.

The big differences between these mortality figures might be attributed to diameter distribution or phloem thickness. Past work (Amman and Baker, in press; Cole and Amman 1969) showed that the mountain pine beetle kills a higher percentage of the large-diameter trees than it does of the small-diameter trees. Although some differences did exist in diameter distributions between the two species, the mountain pine beetle killed more (proportionately) lodgepole pine trees than whitebark trees. For example, 39.9 percent of the trees in the 14- to 16-inch diameter class were lodgepole pine and 30 percent were whitebark pine. Therefore, if the kill had been equal for both species, the mountain pine beetle would have killed 6.4 percent of the lodgepole pine trees, based upon the 4.8 percent mortality of whitebark pine [(39.9/30.0) 4.8 = 6.4 percent]. However, the actual mortality of lodgepole pine was 30.6 percent; this demonstrates that the mountain pine beetle killed a proportionately higher number of trees for this species.

Phloem thickness is another factor that might have been responsible for the differences in mortality between the two species. Amman (1969) showed that survival of mountain pine beetle brood was associated with phloem thickness. However, average phloem thickness (in inches) was greater in whitebark pine as shown in the tabulation below:

Diameter class (Inches)	*Lodgepole pine*	*Whitebark pine*
8-10	0.097	0.107
11-13	.106	.119
14-16+	.108	.134

We would have expected greater mortality in whitebark pine if the mountain pine beetle had selected trees on the basis of phloem thickness. Therefore, this is additional evidence that the mountain pine beetle demonstrated a preference for lodgepole pine on the Togwotee I study area.

In the Togwotee II study area, mortality that could be attributed to the mountain pine beetle remained at low levels for both lodgepole pine and whitebark pine: 2.4 and 3.1 percent, respectively (fig. 2). The overall effects of mountain pine beetle infestation pressure at lower elevations were not evident because Togwotee II was separated by Togwotee I from the infested lodgepole pine stands. There were not any consistent differences in mortality by diameter class between species (table 1). Furthermore, average phloem thickness (in inches) indicates that the food supply in all diameter classes was ample for both species, as shown in the following tabulation:

Diameter class (Inches)	*Lodgepole pine*	*Whitebark pine*
8-10	0.112	0.101
11-13	.116	.113
14-16+	.100	.122

The lower mortality experienced in Togwotee II probably can in part be attributed to the cool temperatures prevailing at higher elevations. It has been proven that cooler temperatures disrupt beetle development.[6] However, the temperatures at Togwotee I

[6]G. D. Amman. Variations in the biology and their significance in dynamics of mountain pine beetle populations. Intermountain Forest and Range Experiment Station, Ogden, Utah (in preparation).

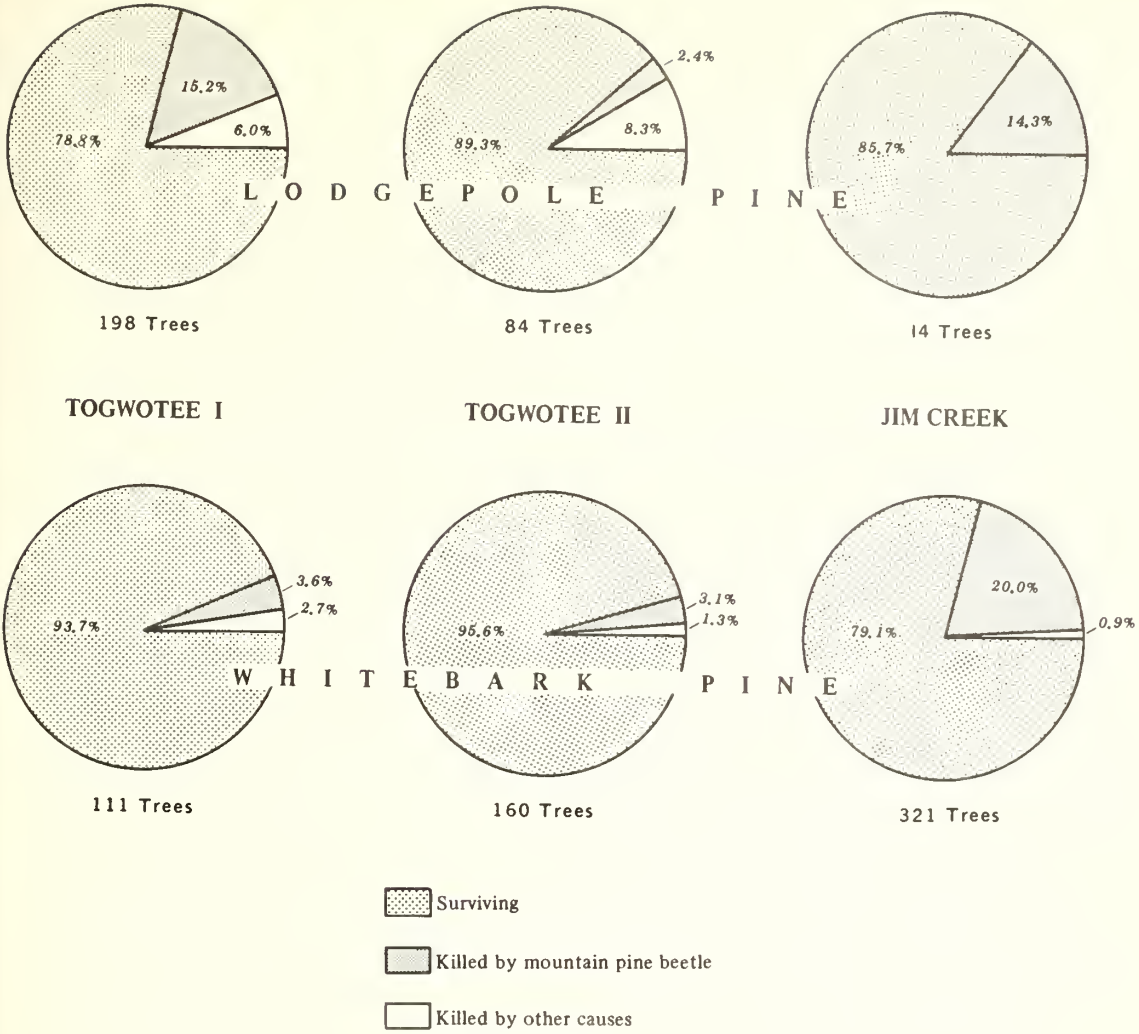

Figure 2.--Living and dead lodgepole and whitebark pines 4 inches d.b.h. and larger in three study areas.

and Togwotee II study areas are so similar that we can only conclude this lower mortality can be directly related to the fact Togowotee II was not located adjacent to the infested lodgepole pine stand. Moreover, conclusions could not be drawn regarding host specificity because of the low amount of tree mortality on the Togwotee II study area.

Situation 2.--An infestation occurred in Jim Creek between 1961 and 1963, which produced heavy mortality (20 percent) in this predominantly whitebark pine stand (75 percent). The lodgepole pine component in this study area was so negligible (3 percent) that the only meaningful comparison of the effects of infestation pressure from beetles reared in whitebark pine on lodgepole pine trees could be made with the trees in the pure lodgepole pine stands located immediately below the study area. Mortality in the lodgepole stands remained low, apparently unaffected by beetles from the whitebark pine broods. Neither tree sizes nor phloem thicknesses appeared to have limited beetle activity in the study area as well as in the uninfested lodgepole pine stand. It is believed that the beetle population increased during years when temperatures were favorable, then declined when temperatures became adverse. Beetle activity should have been enhanced in the lodgepole pine stands because of warmer temperatures. The failure of adult beetles to migrate from the whitebark pine stands to the lodgepole pine stands suggests specificity for the tree species in which the beetle completed its larval development.

Table 1.--*Percent of lodgepole and whitebark pine trees 8 inches d.b.h. and larger killed by the mountain pine beetle, in three diameter classes on Togwotee I and Togwotee II study areas*

D.b.h. (inches)	Species	Trees in sample[1]	Mortality
		TOGWOTEE I	
8-10	Lodgepole pine	40 (28.0)	12.5
	Whitebark pine	25 (35.7)	4.0
11-13	Lodgepole pine	46 (32.1)	13.0
	Whitebark pine	24 (34.3)	8.3
14-16+	Lodgepole pine	57 (39.9)	31.6
	Whitebark pine	21 (30.0)	4.8
Totals	Lodgepole pine	143	--
	Whitebark pine	70	--
		TOGWOTEE II	
8-10	Lodgepole pine	24 (53.3)	0.0
	Whitebark pine	51 (47.2)	2.0
11-13	Lodgepole pine	13 (28.9)	0.0
	Whitebark pine	29 (26.9)	6.9
14-16+	Lodgepole pine	8 (17.8)	12.5
	Whitebark pine	28 (25.9)	3.6
Totals	Lodgepole pine	45	--
	Whitebark pine	108	--

[1]Figures in parentheses represent percent of total number of living and dead trees 8 inches d.b.h. and larger for each species.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1971 - 780 - 437/58 REGION

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-152

December 1971

SITE INDEX FOR LODGEPOLE PINE--A POOR INDICATOR OF SITE PRODUCTIVITY FOR HERBACEOUS PLANTS

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ABSTRACT

Site index for lodgepole pine was tested as a possible indicator of potential for herbaceous vegetation yield following clearcutting. Correlation coefficients were determined for site index and yield of native vegetation, and for site index and yield of a seeded mixture grown both in the field and in the greenhouse. Site index for lodgepole pine has no apparent value in predicting yields of herbaceous vegetation.

Montana's 5.4 million acres of lodgepole pine (*Pinus contorta* Dougl.) received little commercial use until the early 1950's; since then, cutting for poles, pulp, and lumber has increased to an estimated 7,000 acres annually.[2]

Clearcutting, coupled with thinning of subsequent tree regeneration, stimulates herbaceous growth that may provide an important grazing resource for livestock and big game for an estimated 20 years.[3] Indigenous herbage on these clearcuts usually rates only fair both in productivity and in palatability. Therefore, seeding of more desirable forage species appears warranted to gain full advantage of the 20-year grazing potential that these clearcuts offer.

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[2]From files of USDA Forest Service, Northern Region, Missoula, Montana.

[3]Joseph V. Basile and Chester E. Jensen. Grazing potential on lodgepole pine clearcuts in Montana. USDA Forest Serv. Res. Pap. INT-98, 11 p., illus. 1971.

Allocation of forage seeding efforts to secure maximum returns on investment must be predicated on site potential for herbage production. Thus, a means of determining site potential is needed. Basile and Jensen[3] found production of native herbage to be correlated with field capacity of the soil solum and with the sand and potassium content of the B soil horizon. However, because measuring these soil variables is time consuming, I sought a faster method of determining site potential, using site index for lodgepole pine. Since corrected site index[4] purportedly reflects the net effect of all interacting site factors on height growth of lodgepole pine, I assumed that site index would also reflect the net effect of these factors on herbage yields and therefore serve to predict probable results of forage seedings on lodgepole pine clearcuts. The purpose of this study was to test the validity of this assumption.

METHODS

Site indexes for 19 clearcut areas were approximated from measurements on immediately adjacent, uncut stands of lodgepole pine that closely matched the clearcuts in topography, elevation, aspect, and soils. Site indexes were measured as described by Alexander,[4] using a prism with a basal area factor of 10. The 19 clearcut areas were within the Lewis and Clark and the Gallatin National Forests in Montana, east of the Continental Divide.

Correlation coefficients were determined for site index and yields of:

(a) *Native vegetation on the 19 clearcut areas:* On a 1-acre macroplot on each area, all vegetation within 30 circular plots of 4.8 sq. ft. was clipped at ground level near the end of the growing season, dried (60° C. for 24 hrs.), and weighed.

(b) *A seeded forage mixture on the clearcuts:* On 15 of the clearcut areas, a 20 by 20 ft. plot was roto-tilled to a depth of 4 to 6 inches and all vegetation removed. In late September 1967, 75 grams of the following mixture were handseeded and raked into the 20 by 20 ft. plot:

Timothy (*Phleum pratense*)	2 parts
Smooth brome (*Bromus inermis*)	4 parts
Orchardgrass (*Dactylis glomerata*)	4 parts
Tall oatgrass (*Arrhenatherum elatius*)	2 parts
Kentucky bluegrass (*Poa pratensis*)	2 parts
Yellow sweetclover (*Melilotus officinalis*)	2 parts

After two growing seasons, yields were sampled by clipping, drying, and weighing all vegetation within six 4.8 sq. ft. subplots in each plot.

(c) *A seeded forage mixture grown in the greenhouse:* Separate soil samples from the A and B horizons of all clearcut areas were air-dried, sieved through 1/4 inch mesh, potted in triplicate, and seeded with the same species that were used in the field trials. Seedlings were thinned to two plants per species per pot. An automatic watering system kept all pots well watered. When they had matured, all plants were harvested, dried, and weighed.

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[4]Robert R. Alexander. Site indexes for lodgepole pine, with corrections for stand density: instructions for field use. U.S. Forest Serv. Res. Pap. RM-24, 7 p., illus. 1966.

RESULTS AND CONCLUSIONS

Site index for the 19 sampled sites ranged from 38 to 84; understory production, from 110 to 1,100 lbs./acre; and elapsed time since clearcutting, from 2 to 16 years. Because understory production is related to elapsed time since clearcutting,[3] the time effect was fitted before assessing the relation of understory production to site index. After fitting the time effect, site index accounted for only 1 percent of the variation in production. As an additive or interacting term with several topographic and soil variables in a number of regression models,[3] the contributions of site index to accountable variation were negligible. Apparently this measure of site potential for tree growth is poorly related to production of indigenous understory vegetation.

Two years after seeding the roto-tilled plots, production of seeded species ranged from 100 to 1,154 lbs./acre (average: 464), and total production (seeded species plus reinvading native plants) ranged from 170 to 1,402 lbs./acre (average: 597). Herbaceous plant production was not significantly correlated with site index; coefficients of determination (r^2) were 0.02 and 0.04 for seeded species and for total vegetation, respectively.

Nonsignificant correlations also were obtained for site index and forage yields in the greenhouse trial. Coefficients of determination for grasses grown in soils from the A and the B horizons were 0.02 and 0.07, respectively. For total production of grasses plus *Melilotus*, r^2 values were 0.01 for the A horizon, and 0.08 for the B horizon.

The failure of site index to predict understory yields may be attributed to differences between trees and understory vegetation as to major rooting zones, periods of active growth, and requirements for, and efficient use of, moisture and nutrients. Furthermore, height-age relations of lodgepole pine reflect the sum of growing conditions over several decades, whereas understory yields, for the most part, reflect growing conditions for one season only.

Site index is used as a measure of site potential for lodgepole pine growth, but it apparently is of no value as an indicator of potential production of associated understory vegetation, nor of soil productivity for the mixture of grass species tested.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
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USDA Forest Service
Research Note INT-153

January 1972

CHILLING REQUIREMENTS FOR BREAKING DORMANCY OF WESTERN WHITE PINE SEEDLINGS

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ABSTRACT

*One- and 2-year-old western white pine (*Pinus monticola *Dougl.) seedlings representative of five full-sib families were artificially chilled at 40° F. from 0 to 14 and from 8 to 20 weeks, respectively. After chilling, the seedlings were placed in a growth chamber and exposed to a 16-hour photoperiod and a 70°-50° F. temperature regime. Chilling for at least 14 weeks was necessary for seedlings to approach maximal shoot elongation.*

Most temperate zone woody plants have a period of winter dormancy. Such plants must be subjected to cool temperatures for extended periods before they can be released from dormancy and begin normal growth the following spring. Although most of the early work on dormancy release was done on fruit trees (see Samish 1954; Romberger 1963; or Vegis 1964, for general reviews), a number of recent papers have reported chilling requirements for forest trees.

Nienstaedt (1966, 1967) examined the chilling requirements of seven species of spruce and found that all required 6 to 8 weeks at 40° F. to break dormancy promptly when returned to growing conditions. In other work, Dormling and others (1968) found that an optimum growth cycle could be maintained for Norway spruce (*Picea abies* (L.) Karst.) by means of a 4-week chilling period. Berry (1965) reported that eastern white pine (*Pinus strobus* L.) required 8 weeks of chilling for "normal" growth.

Examples of the chilling requirements of deciduous forest trees are sweetgum (*Liquidambar styraciflua* L.), 7 to 9 weeks (Farmer 1968); and red maple (*Acer rubrum* L.), 4 weeks (Perry and Wang 1960). Kriebel and Wang (1962) reported that 13 weeks were needed to achieve most rapid bud-break in sugar maple (*Acer saccharum* Marsh.). Perry and Wang (1960), Kriebel and Wang (1962), and Nienstaedt (1967) found that seedlings of

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the same species from different provenances had different chilling requirements. They reported that seedlings from milder climates usually required less chilling than did those from colder climates. Perry and Wang (1960) also detected differences in chilling requirements among the progenies of individual mother trees from a single area.

On trees that have not had sufficient chilling for terminal buds to develop normally, lateral buds often grow and cause misshapen trees (Holst 1962; Perry and Wang 1960). Conversely, Perry and Wang also found that excess chilling delayed the start of growth for a number of red maple progenies.

The study reported here determined the period of artificial chilling needed by western white pine (*Pinus monticola* Dougl.) seedlings to break dormancy and to produce "normal" growth. The information will be of value when seedlings are to be grown in a greenhouse or a growth chamber.

MATERIALS AND METHODS

Seed from five crosses among 10 trees at elevations ranging from 2,700 to 3,500 ft. were stratified for 100 days and sown during April 1968, in 1-1/2-inch "Jiffy" peat pots containing equal parts of forest soil, sand, and peat moss. When sufficient seed had germinated, the 3- to 4-week-old seedlings and their pots were placed in 8-inch-deep wooden flats containing the same soil mixture. Eight seedlings from each of the five families were randomly planted in each of 17 flats. The flats were then placed in a lathhouse until the seedlings had completed their normal first-year growth cycle.

Artificial chilling was begun in mid-September when all seedlings had set their first-year buds; plants were chilled in a cold room at 40±2° F. Fluorescent lights were operated to provide 500 ft.-c. of light for 8 hours each day. Nine flats of seedlings were subjected to various chilling treatments the first year: One received no chilling, seven were chilled for periods ranging from 2 to 14 weeks by 2-week increments and the last, the control, was held in the lathhouse to receive "natural chilling" for 18 weeks. The other eight flats were kept in the lathhouse until the end of the second summer.

Following the prescribed chilling period, the flats were moved to a growth chamber set to provide a 16-hour "day," a light intensity of 3,000 ft.-c., and a temperature of 70° F. followed by an 8-hour "night" at 50° F. The height of each seedling was measured when the flats were transferred to the growth chamber and at 1-week intervals thereafter for 13 weeks. At the end of that time, the seedlings had grown and again set buds. An analysis of variance was calculated for the total epicotyl growth. Differences between treatment means were compared by the method presented by Snedecor (1956, page 253).

In order to determine the chilling requirements of 2-year-old seedlings and to compare the results with those for 1-year old seedlings, we left the remaining eight flats in the lathhouse through the winter and the second summer. However, because of the first-year results, we eliminated the shortest chilling periods and added some longer ones. The resulting chilling periods for the 2-year-old seedlings were as follows: 8, 10, 12, 14, 16, 18, and 20 weeks. We left the eighth flat, the control, in the lathhouse for 22 weeks of natural chilling. Cold room and growth chamber conditions were the same as for the 1-year material and the same measurement schedule was followed.

We expanded our statistical analysis of second-year data to evaluate family differences and family X treatment interaction effects, in addition to comparing treatment means.

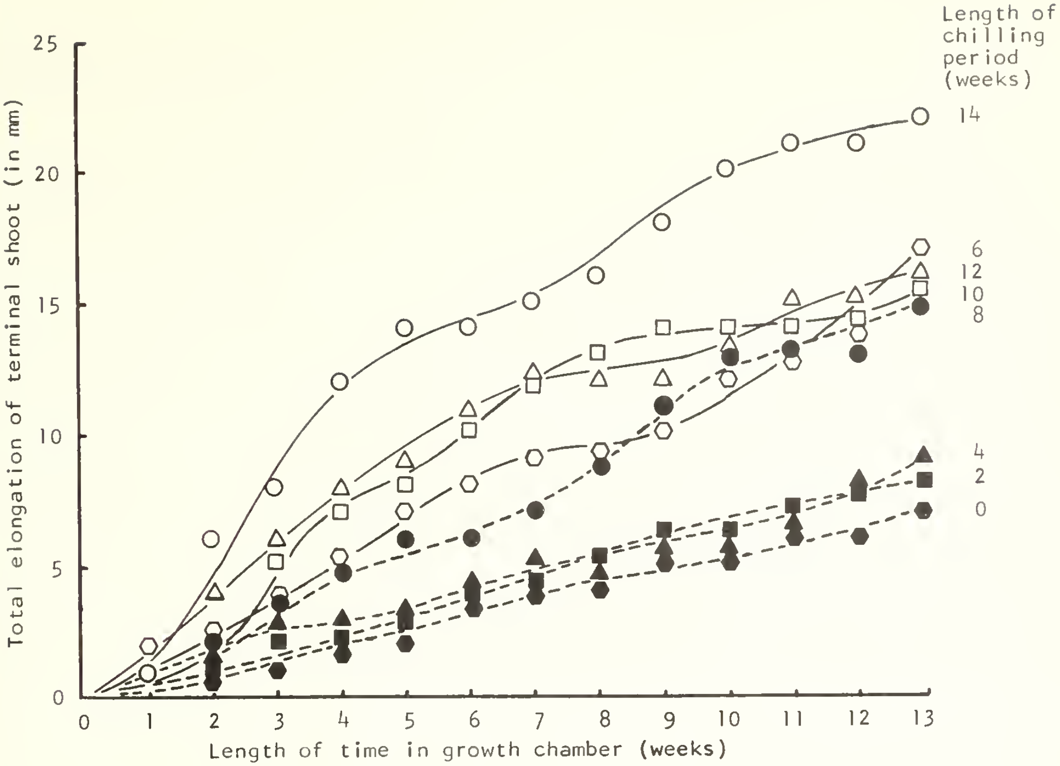

Figure 1.--Terminal elongation of 1-year-old western white pine seedlings chilled for various periods of time. (All curves are hand drawn.)

RESULTS AND DISCUSSION

One-year-old seedlings.--Seedlings given progressively longer periods of chilling grew at progressively faster rates and made more total epicotyl growth than those that received less chilling (fig. 1). Most seedlings continued to make some height growth throughout the 13 weeks they were in the growth chamber.

Total epicotyl length of seedlings chilled for 14 weeks was significantly[2] greater than those of all seedlings chilled for shorter periods. Differences among seedlings chilled for 6, 8, 10, or 12 weeks were not significant, but all seedlings given those treatments grew significantly more than those chilled for 0, 2, or 4 weeks. The 0-, 2-, and 4-week treatments did not differ significantly. The box of seedlings left in the lathhouse to serve as a control was frozen solid during unusually cold weather. Shortly after we brought these control seedlings indoors to start their growth period, most showed evidence of damage or were dead. Consequently, we had no control for effective comparison. Because each additional 2 weeks of chilling resulted in additional growth of the seedlings, the minimum chilling needed to achieve optimum growth might not have been reached. However, the total growth of the seedlings chilled for 14 weeks approximated that of seedlings in our nursery operations.

Trauma-induced simple leaves developed and lateral buds often elongated abnormally on seedlings chilled for very short periods. When this occurred, bushy, misshapen seedlings resulted. Exposure of the seedlings to shorter or longer photoperiods in the growth chamber might have resulted in quite different growth patterns. The 16-hour

[2]All significance tests were made at the 5-percent probability level.

photoperiod we chose might have had some long-day promotional effects, particularly on seedlings chilled for short periods, but it was chosen to approximate the natural photoperiod at the time trees in the field resume growth in the spring.

Two-year-old seedlings.--The pattern of shoot elongation for the 2-year-old seedlings (fig. 2) was much different than for 1-year-old seedlings. Whereas almost all 1-year-old seedlings grew at an almost constant rate for 13 weeks, the 2-year-old ones completed most of their growth in a 4- to 8-week period, depending on the chilling treatment.

Differences in the first and second year shoot-elongation patterns might indicate that artificial chilling was begun too early the first year (mid-September) to allow sufficient time for bud maturation. During the year the seeds germinate, western white pine seedlings grown in a nursery commonly do not complete growth until early September. In contrast, growth during the second year is usually confined to a 5- to 6-week period that ends in early June. Dormling and others (1968) found that a 4-week bud-maturation period prior to chilling was required in an optimal cycle for Norway spruce.

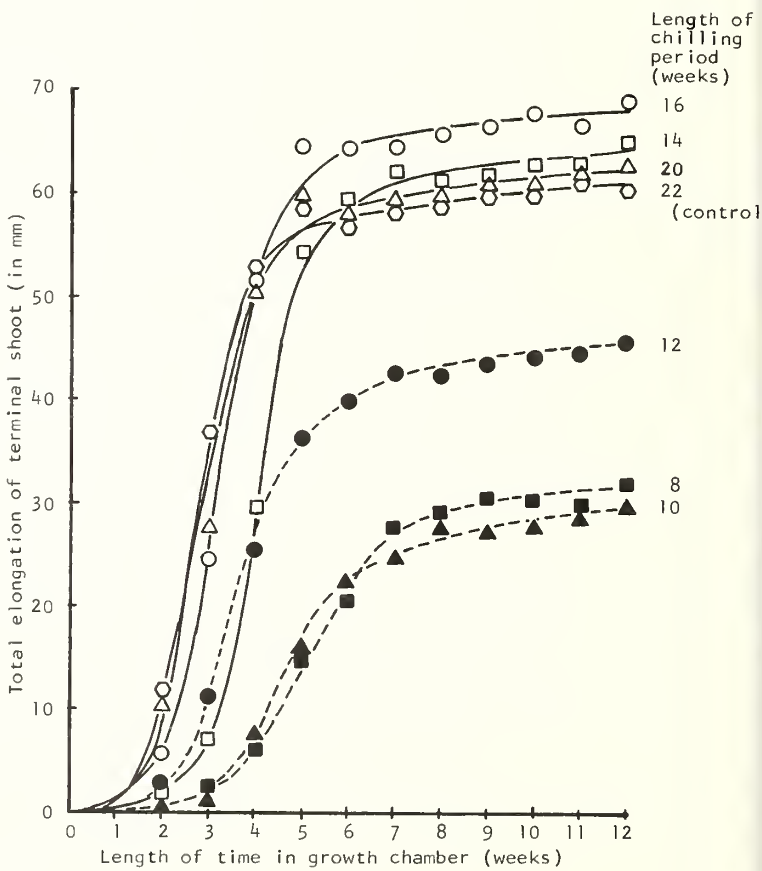

Figure 2.--Terminal elongation of 2-year-old western white pine seedlings chilled for various periods of time.

Seedlings chilled 16 or more weeks had begun growth by the end of the second week in the growth chamber and had completed 95 percent of their total shoot elongation by the end of the fifth week. Growth in seedlings chilled 12 or 14 weeks did not begin until the third week, but then continued until the seventh week. Seedlings chilled 8 or 10 weeks did not grow much until the fourth week, but continued to grow until the eighth or ninth week.

Total new epicotyl growth did not differ significantly among seedlings that had received 14, 16, 20, or 22 (lathhouse control) weeks of chilling, but the growth of all differed significantly from that of seedlings chilled for 8, 10, or 12 weeks. Seedlings chilled for 12 weeks grew significantly more than those chilled for 8 or 10 weeks, but the latter two did not differ significantly. A fungal growth developed on the box of seedlings chilled for 18 weeks and the seedlings were severely damaged; they were eliminated from the test.

Further statistical analysis of the data showed that the final total height of individual families differed, but the family X treatment interaction was not significant. Apparently, all families tested had essentially the same chilling requirements.

The trend of seedlings chilled for more than 16 weeks to make more rapid initial growth (but slightly less total growth) was significant, but (as mentioned earlier) the total growth for the 14-, 16-, 20-, and 22-week treatments did not differ significantly.

CONCLUSIONS

Both 1-year-old and 2-year-old western white pine seedlings appear to require a minimum of 14 weeks of artificial chilling at 40° F. (16 weeks probably are near optimum) to obtain maximum "normal" growth. Additional chilling will promote faster initial growth, but might result in less total growth. Under the growth chamber conditions we used, most seedlings made some growth, but those chilled for less than 14 weeks did not reach their growth potential.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-154

February 1972

A FIBERGLASS CAGE FOR REARING BARK BEETLES IN SMALL LOG SECTIONS

Richard F. Schmitz[1]

ABSTRACT

Construction of a fiberglass cage, consisting of a lid and tapered cylindrical container portion that proved satisfactory for rearing bark beetles, is described. The cage is strong, lightweight and, despite rough handling, retains its original shape and the lid its insect-tight seal.

Laboratory study of bark beetles often requires specialized rearing containers, such as those described by Germain and Wygant[2] and Clark and Osgood.[3] A cylindrical fiberglass cage that proved to be highly satisfactory for rearing the pine engraver, *Ips pini* (Say), in an environmental chamber is shown in figure 1.[4]

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[1]Associate Entomologist, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho. The author gratefully acknowledges the help of Robert D. Oakes in preparation of figure 3.

[2]Charles J. Germain and Noel D. Wygant. A cylindrical screened cage for rearing bark beetles. U.S. Forest Serv. Res. Note RM-87. 1967.

[3]E. W. Clark and E. A. Osgood, Jr. An emergence container for recovering southern pine beetles from infested bolts. J. Econ. Entomol. 57:783. 1964.

[4]Cage was constructed by Whitmire Fiberglass, Evaro, Mont. Mention of proprietary products does not necessarily imply its endorsement by the U.S. Department of Agriculture.

Figure 1.--Fiberglass cage containing log section infested by pine engraver beetles.

MATERIALS AND SPECIFICATIONS

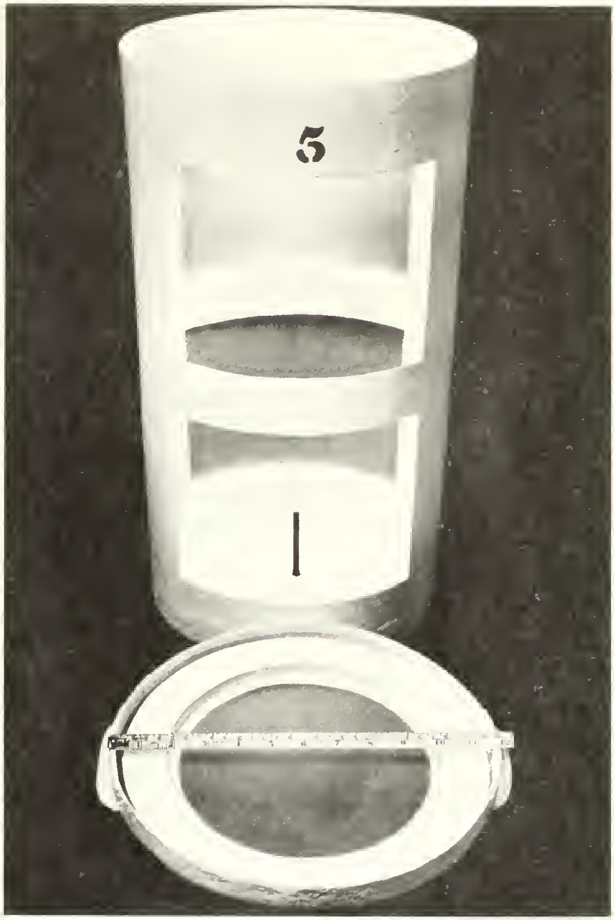
The cage consists of a lid and a tapered cylindrical container (fig. 2). Dimension and construction details are illustrated in figure 3. The container portion was constructed by either the "hand lay-up" or catalyst injection gun method. For the "hand lay-up" method, a 2-oz. soluble glass mat[5] was formed around a wooden mold sprayed with a white finishing resin.[6] When the mat was in place, a coat of general purpose polyeste laminating resin was applied. An injection gun was used to spray the fiberglass and the laminating resin directly over the white finishing resin on later models. The "hand lay-up" method provides greater control of wall thickness, which can vary from 1/16 to 1/8 in., but is slower and more costly.

The cage bottom consisted of a plywood core 10 in. in diameter and 1/2 in. thick A carriage bolt, 3 in. long and 1/4 in. in diameter, that protruded through the center was sealed in 1/4-in. layers of glass mat and resin on the cage bottom. The plywood provided additional rigidity and sufficient thickness to hold the carriage bolt in place

[5]Binder Glass Mat, a product of American Cyanamid Co.

[6]Selectron 5872, a white gel coat resin, manufactured by Pittsburgh Plate Glass Co., Pittsburgh, Pa.

Figure 2.--Fiberglass cage from which lid has been removed to show construction details.



All cage lids were constructed by the "hand lay-up" method to insure a proper fit. This method was also used to attach two handles to the lid (fig. 2). A 1½-in.-wide by 1/2-in.-thick plywood ring, 11¼ in. in outside diameter, served as the base for the coating of glass mat and resin. The outside lip of the lid overlapped the top edge of the container portion by 3/4 in. The lid was fitted snugly by filing or sanding the top edge of the container.

A saber saw, fitted with a fine-toothed blade for cutting plastic, was used to make openings in the lid and in the sides of the cage (fig. 2). Each of the four openings in the cage walls measured 6½ in. by 9 in., while the opening in the lid was 10 in. in diameter. These openings were covered by a plastic monofilament 32- by 32-mesh screen[7] and affixed to the inside cage wall by a clear waterproof silicon base sealant.[7] Cages cost about $18.00 in 1970.

ADVANTAGES

Fiberglass provides several advantages in cage construction not obtainable from some other materials. It is strong, lightweight, and easily cut and sanded. Because of the resiliency of fiberglass, the cage can be squeezed or bent during handling, and yet retain its original shape and the insect-tight seal of its lid. The white finishing resin interior bonds to the fiberglass wall producing resistance to chipping and abrasion that is superior to paints. Odors emitted by the curing resin or the plastic screen dissipated rapidly and apparently had no effect on the beetles.

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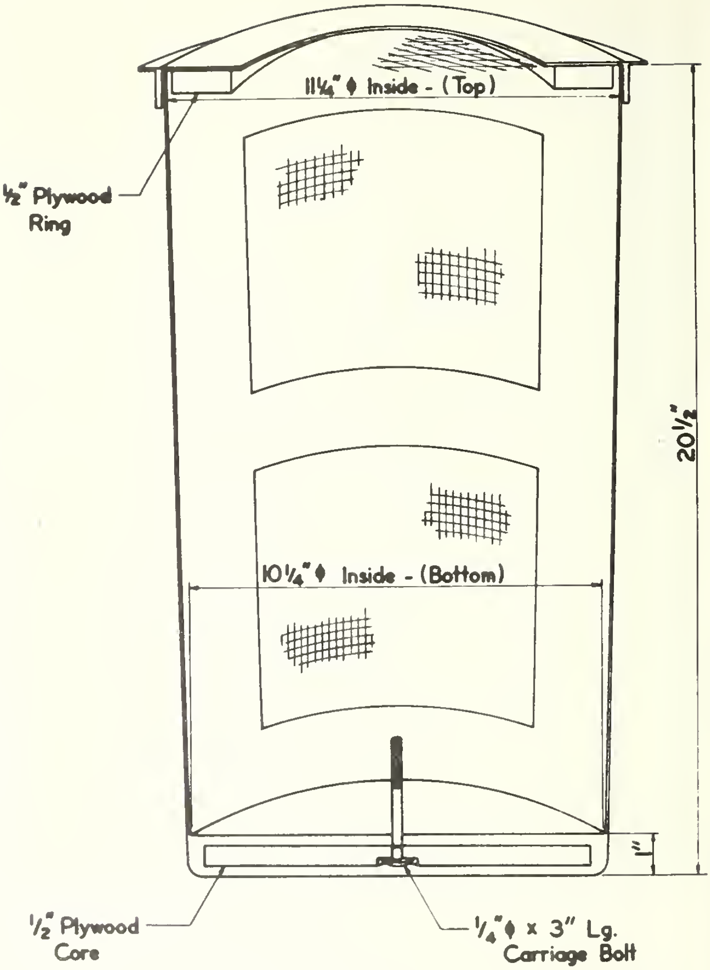
[7]Manufactured by Dow Corning Corp., Midland, Mich.

Figure 3.--Cross section of fiberglass cage showing dimensions.



The cage can accommodate a tree bole section 18 in. long and 8 in. in diameter. Five screened openings permit observations of the contents and, at the same time, allow moisture to dissipate. The lid is insect-tight, but it can easily be removed to introduce or to collect beetles. The absence of corners and the white interior aid collection of insects. The enclosed bole section is steadied by inserting the carriage bolt protruding from the cage bottom into a hole bored into the center of the bole. Space needed for storage of cages was minimized by nesting the tapered containers.

APPLICATION

The cage is suitable for rearing bark beetles that breed in small logs. Parent *I. pini* beetles were introduced into cages containing green stem sections which they infested. Emerging progeny tended to avoid the smooth cage walls and concentrated on the screened openings. Consequently, they were easily collected by sliding a container along the screen. Beetles obtained were free of injuries, which are common in jar-type light traps despite the use of shredded paper for footing. However, a container and lid left without screened openings could be fitted with a jar light trap if one were require

The cage might also be adapted for rearing insects dependent on small potted plants The drainage hole in the bottom of the pot could be placed over the carriage bolt protruding from the bottom of the cage to stabilize the plant.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-155

February 1972

A PRELIMINARY LIST OF INSECTS AND MITES THAT INFEST SOME IMPORTANT BROWSE PLANTS OF WESTERN BIG GAME

M. M. Furniss[1]

ABSTRACT

The insects that damage some important browse plants on western big game ranges are listed alphabetically by their scientific names. The host plants which are included belong to the genera Amelanchier *(serviceberry),* Ceanothus, Cercocarpus *(mountain mahogany),* Purshia *(bitterbrush) and* Salix *(willow).*

Shrubs of the genera *Amelanchier, Ceanothus, Cercocarpus, Purshia*, and *Salix* are important browse for western big game. During winter, such animals as deer, elk, moose, antelope, bighorn sheep, and mountain goat might depend on these woody plants for their survival. The condition of the plants affects their nutritive value to animals and is lessened by damage done by insects. However, the relationship of insects and browse plants has not received much study (Furniss and Krebill in press).

This preliminary list is published to aid those concerned with management or study of the shrubs. It includes only the insect species believed to damage their host plants. Omitted are all parasitic and predacious species as well as those that appear to have been merely perching on the plants. Often, the damaging stage of insects was immature and difficult to identify, sometimes even to genus. Insects not identifiable to genus are omitted.

Most records have been obtained recently during surveys of insects on the shrubs involved in Idaho and, to a lesser extent, in adjacent States. Colleagues have provided information on insect groups and have assisted in the surveys, as noted in Acknowledgments. Collections have been most intensive on bitterbrush, a plant frequented by large numbers and many kinds of insects.

[1]Principal Entomologist, stationed in Moscow, Idaho at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

The list is organized alphabetically by scientific names of the host plants and insects. That is, the generic plant names are in alphabetical order and the insects that affect them are presented alphabetically, first by order, then by family, genus, and species. The parts of the plant that are damaged are indicated when known and references are noted. In addition to the references noted, Essig (1956) is a helpful general reference. The list is published with the hope that it will stimulate greater interest in these insects and that a more complete and useful list will eventually result.

HOST: *AMELANCHIER* SPP. (SERVICEBERRY)

Species	Part affected	Reference
COLEOPTERA		
Buprestidae		
Agrilus vittaticollis (Randall)	Stem	
Curculionidae		
Magdalis sp. prob. *salicis* Horn	Stem	
Scolytidae		
Chaetophloeus heterodoxus (Casey) (= *Renocis*)	Stem	Chamberlin 1955
DIPTERA		
Cecidomyiidae		
Contarinia sp.	Fruit	
Trishormomyia ?canadensis (Felt)	Leaf galls	
HOMOPTERA		
Aphididae		
Prociphilus alnifoliae alnifoliae (Wms.)	Leaves	
Coccidae		
Phenacoccus dearnessi King		McKenzie 1967
Diaspididae		
Lepidosaphes ulmi (Linn.)	Stem	
HYMENOPTERA		
Tenthredinidae		
Hoplocampa sp.	Fruit	
LEPIDOPTERA		
Nymphalidae		

Species	Part affected	Reference
Nymphalis californica (Boisd.)	Leaves	Bryant 1911 Storer 1933 Tevis 1953
Psychidae		
Apterona helix Siebold	Leaves	Robinson 1953
Lasiocampidae		
Malacosoma californicum (Packard)	Leaves	Stehr & Cook 1968
Tortricidae		
Archips cerasivorana Fitch	Leaves	

HOST: *CEANOTHUS* SPP. (CEANOTHUS)

Species	Part affected	Reference
COLEOPTERA		
Buprestidae		
Acmaeodera nexa Fall	Stem	
angelica Fall	Stem	
mariposa Horn	Stem	
vandykei Fall	Stem	
sinuata sexnotata Van Dyke	Stem	
Anthaxia deleta deleta LeC.	Stem	
Chrysobothris mali Horn	Stem	
Dicerca horni Crotch	Stem	
Polycesta californica LeC.	Stem	
Cerambycidae		
Anoplodera crassipes LeC.	Stem	
DIPTERA		
Cedidomyiidae		
Asphondylia ceanothi Felt	Buds	
HEMIPTERA		
Pentatomidae		
Euschistus conspersus Uhler	Immature fruit	
Holcostethus abbreviatus (Uhler)		
Tingidae		
Corythucha obliqua Osborn & Drake	Leaves	

Species	Part affected	Reference
HOMOPTERA		
Aphididae		
Aphis ceanothi Clarke	Leaves	
Cercopidae		
Clastoptera ovata Doering	Stem	
Coccidae		
Pseudococcus maritimus Ehrhorn		McKenzie 1967
Puto albicans McKenzie		McKenzie 1967
yuccae Coquillet		McKenzie 1967
Rhizoecus bicirculus McKenzie		McKenzie 1967
Spilococcus ceanothi McKenzie		McKenzie 1967
quercinus McKenzie		
Psyllidae		
Arytaina robusta Crawford	Leaves	
HYMENOPTERA		
Cimbicidae		
Zaraea americana Cress.		
Eurytomidae		
Eurytoma squamosa Bugbee	Seed	
LEPIDOPTERA		
Geometridae		
Itame quadrilineata (Pack.)	Leaves	
Nematocampa filamentaria Gn.	Leaves	
Scopula junctaria quinquelinearia (Pack.)	Leaves	
Lymantriidae		
Orgyia vetusta gulosa (Boisd.) (= *Hemerocampa*)	Leaves	Atkins 1958 Brown & Eads 1965 Furniss & Knopf 1971 Volck 1907
Lasiocampidae		
Malacosoma californicum (Packard)	Leaves	
Nymphalidae		
Nymphalis californica (Boisd.)	Leaves	See serviceberry
Tortricidae		
Archips argyrospilus (Wlk.)	Leaves	

Species	Part affected	Reference
ACARINA		
Eriophyidae		
Aceria ceanothi (K.)	Leaf galls	

HOST: *CERCOCARPUS* SPP. (MOUNTAIN MAHOGANY)

Species	Part affected	Reference
COLEOPTERA		
Buprestidae		
Acmaeodera knowltoni Barr	Stem	
vandykei Fall	Stem	
idahoensis Barr	Stem	
Anthaxia deleta deleta LeC.	Stem	
simiola Casey	Stem	
Chrysobothris mali Horn	Stem	
Dicerca horni Crotch	Stem	
Polycesta californica LeC.	Stem	
Scolytidae		
Chaetophloeus heterodoxus (Csy.) (= *Renocis*)	Stem	Chamberlin 1955
DIPTERA		
Tephritidae		
Paroxyna spp.		
HEMIPTERA		
Miridae		
Microphyllelus sp.		
Psallus alnicola Douglas & Scott		
Pentatomidae		
Thyanta pallidovirens (Stål)	Stem, leaves	
HOMOPTERA		
Cicadidae		
Platypedia putnami (Uhler)	Stem	
Coccidae		

Species	Part affected	Reference
Lecanium sp.		
Psyllidae		
Euphalerus adustus Tuthill		
Psylla sp., near *acuta* Crawford		
Psylla magna Crawford		
HYMENOPTERA		
Tenthredinidae		
Amauronematus sp.	Stem	
LEPIDOPTERA		
Ethmiidae		
Ethmia discostrigella (Chambers)	Leaves	
Geometridae		
Anacamptodes clivinaria profanata (B. & McD.)	Leaves	Furniss & Barr 1967 Furniss 1971a
Marmopteryx animata Pears.	Leaves	
Lasiocampidae		
Malacosoma californicum (Packard)	Leaves	Stehr & Cook 1968
Lyonetiidae		
Bucculatrix sp.	Leaves	

HOST: *PURSHIA TRIDENTATA* (BITTERBRUSH)

Species	Part affected	Reference
COLEOPTERA		
Buprestidae		
Acmaeodera purshiae Fisher	Stem	
Chrysobothris deleta LeC.	Stem	
Chrysomelidae		
Altica bimarginata Say		
Cryptocephalus sanguinicollis sanguinicollis Suffrian		
Chrysomela lineatopunctata Forster		
Monoxia sp. poss. *consputa* (LeC.)		
Pachybrachis sp.		
Curculionidae		
Triglyphulus sp.		

Species	Part affected	Reference
DIPTERA		
Cecidomyiidae		
Dasineura sp.		
Leucopis sp.		
Mayetiola sp. (= *Phytophaga*)	Fruit	
HEMIPTERA		
Cicadidae		
Platypedia sp.	Stem	
Coreidae		
Harmostes reflexulus (Say)		
Lygaeidae		
Nysius angustatus Uhler		
Geocoris pallens Stål		
Miridae		
Adelphocoris rapidus (Say)		
Atractotomus purshiae Froeschner	Leaves	
Capsus simulan (Stål)		
Ceratocapsus sp.		
Deraeocoris fulgidus (V.D.)		
Labops hirtus Knight		
Psallus pilosulus (Uhler)		
Pentatomidae		
Apateticus crocatus (Uhler)		
Brochymena quadripustulata (Fab.)		
Holcostethus abbreviatus (Uhler)	Leaves	
Chlorochroa ligata (Say)	Leaves	
sayi (Stål)	Leaves, seed	Caffrey & Barber 1919
Thyanta pallidovirens (Stål)	Leaves	
Zicrona caerulea (Linn.)		
Scutelleridae		
Eruygaster sp.		
Homaemus bijugis Uhler		
Tingidae		
Gargaphia opacula Uhler	Leaves	

Species	Part affected	Reference
HOMOPTERA		
Aphididae		
Macrosiphum avenae (Fab.)		
purshiae Palmer		
Cercopidae		
Aphrophora permutata Uhler		
Cicadellidae		
Aceratagallia sp.		
Erhthroneura sp.		
Gyponana sp.		
Neocoelidia sp.		
Osbornellus borealis DeLong and Mohr		
Paraphlepsius sp.		
Scaphytopius sp.		
Cicadidae		
Platypedia sp.	Twigs	
Coccidae		
Anisococcus quercus (Ehrhorn)		McKenzie 1967
Lecanium cerasifex Fitch	Stem	
Phenacoccus eriogoni Ferris		McKenzie 1967
Diaspididae		
Lepidosaphes ulmi (Linn.)	Stem	
Psyllidae		
Arytaina pubescens Crawford		
Psylla coryli Patch	Fruit	
hirsuta (Tuthill)		
media Tuthill	Leaves	
LEPIDOPTERA		
Crambidae		
Crambus plumbifimbriellus Dyar		
Gelechiidae		
Filatima sp. (near *abactella*)	Leaves	
Filatima sperryi Clarke	Leaves	
Gelechia mandella Busck.	Leaves	
Geometridae		

Species	Part affected	Reference
Anacamptodes clivinaria profanata (B. & McD.)	Leaves	See mountain mahogany
Chlorosea sp. prob. *margaretaria* Sperry	Leaves	
Chlorosea nevadaria Pack.	Leaves	
Itame colata (Grt.)	Leaves	
Marmpoteryx marmorata Pack.	Leaves	
Semiothisa californiaria (Pack.)	Leaves	
denticulata sexpuncta Bates	Leaves	
Lasiocampidae		
Malacosoma californicum (Packard)	Leaves	Stehr & Cook 1968
Lymentriidae		
Orgyia vetusta gulosa (Boisd.)	Leaves	See ceanothus
Psychidae		
Apterona helix Siebold	Leaves	Robinson 1953
Pyralidae		
Ephestiodes erythrella Ragonot	Leaves	
Myelopsis coniella (Rag.)	Leaves	
Saturniidae		
Hemileuca nuttalli Strecker	Leaves	
Tortricidae		
Choristoneura rosaceana (Harr.)		
Sparganothis tunicana (Wism.)	Seedlings	
Yponumeutidae		
Trachoma walsinghamiella Bsk.	Leaves	
ORTHOPTERA		
Acrididae		
Melanoplus sanquinipes sanquinipes (Fab.)		
bivittatus (Say)		
Oedaleonotus enigma (Scudder)		
Schistocerca lineata Scudder		
Spharagemon equale (Say)		
THYSANOPTERA		
Thripidae		
Frankliniella occidentalis (Pergande)	Buds & flowers	Bryan & Smith 1956

Species	Part affected	Reference
ACARINA		
Eriophyidae		
Aceria kraftella K.	Leaf galls	Kiefer 1959
Aceria tridentatae K.	Twig galls	
Phytoseiidae		
Typhlodromus mcgregori Chant		
Tetranychidae		
Bryobia sp.	Leaves	
Eotetranychus perplexus (McG.)	Leaves	

HOST: *SALIX* SPP. (WILLOWS)

Species	Part affected	Reference
COLEOPTERA		
Buprestidae		
Agrilus politus (Say)	*Stem*	
Buprestis langi Mann.	Stem	
Chrysobothris azurea LeC.	Stem	
mali Horn	Stem	
femorata (Oliv.)	Stem	
Poecilonota fraseri Chamberlin	Stem	
Polycesta californica LeC.	Stem	
Cerambycidae		
Anoplodera aspera (LeC.)	Stem	
Dendrobias mandibularis reductus Casey		Linsley 1962
Hyperplatys sp.	Stem	
Ipochus fasciatus LeC.		
Malacopterua tenellus (Fab.)		Linsley 1962
Necydalis diversicollis Schaeffer		
Oberea quadricallosa LeC.		
Phymatodes blandus (LeC.)		Linsley 1964
Rosalia funebris Mots.		Linsley 1964
Saperda spp.	Stem	
Stenosphenus nigricornis Fisher		Linsley 1963
debilis Horn		Linsley 1963
Synaphaeta quexi (LeC.)		

Species	Part affected	Reference
Xylotrechus insignis (LeC.)		Linsley 1964
mormonus (LeC.)	Stem	
nunenmacheri Van Dyke		Linsley 1964
Chrysomelidae		
Altica ambiens (LeC.)	Leaves	
Calligrapha verucosa Suff.	Leaves	
Chrysomela sp. prob. *confluens* Rogers	Leaves	
Chrysomela lineatopunctata Forster	Leaves	
Disonycha sp. prob. *latiovittata* Hatch	Leaves	
Curculionidae		
Anthonomus haematopus Boh.		
Magdalis gracilis LeC.		
Sternochetus lapathi (Linn.) (=*Cryptorhynchus*)	Stem	Furniss 1971b Harris & Coppel 1967
Nitidulidae		
Cryptarcha ampla Er.	Stem	
Lobiopa undulata (Say)		
Scolytidae		
Cryphalus nitidus (Sw.)	Stem	
Xyleborus saxeseni (Ratz.)	Stem	
dispar (Fab.)	Stem	
DIPTERA		
Agromyzidae		
Agromyza sp.	Galls	
Cecidomyiidae		
Mayetiola rigidae (O.S.)	Galls	
Rhabdophaga sp.	Galls	
HEMIPTERA		
Tingidae		
Corythucha salicata Gibson	Leaves	
HOMOPTERA		
Aphididae		
Chaitophorus nigrae Oestlund	Galls	
Coccidae		

Species	Part affected	Reference
Pseudococcus obscurus Essig		
Diaspididae		
Lepidosaphes ulmi (Linn.)	Stem	
HYMENOPTERA		
Argidae		
Arge clavicornis (Fab.)		
Cimbicidae		
Cimbex americana Leach		
pacifica Cresson		
Trichiosoma triangulum Kirby		
Eurytomidae		
Eurytoma sp.	Galls	
Tenthredinidae		
Amauronematus spp.	Catkins, foliage	
Caliroa labrata MacGillivray		
Euura breweriae E. L. Smith	Stem gall	E. L. Smith 1968, 1970
exiquae E. L. Smith	Stem gall	E. L. Smith 1968, 1970
geyerianae E. L. Smith	Stem gall	E. L. Smith 1968, 1970
lasiolepis E. L. Smith	Stem gall	E. L. Smith 1968, 1970
lemmoniae E. L. Smith	Stem gall	E. L. Smith 1968, 1970
scoulerianae E. L. Smith	Stem gall	E. L. Smith 1968, 1970
Messa wuestneii (Kunow)	Leaf miner	
Nematus chalceus (Marlatt)		
occidentalis (Marlatt)		
oligospilus Foerster		
Phyllocolpa sp.	Leaf edge roll	
Pontania californica Marlatt	Leaf gall	
pacifica Marlatt	Leaf gall	
Pristiphora spp.		
Trichiocampus irregularis (Dyar)		
LEPIDOPTERA		
Aegeriidae		
Aegeria tibialis pacifica (Hy. Edw.)	Stem	
Synanthedon albicornis (Hy. Edw.) (=*Aegeria*)	Stem	

Species	Part affected	Reference
Arctiidae		
Hyphantria cunea (Drury)	Leaves	
Cossidae		
Prionoxystus robiniae (Peck)	Stem	
Lasiocampidae		
Malacosoma californicum (Packard)	Leaves	Stehr & Cook 1968
disstria Hübner	Leaves	
Lymantriidae		
Orgyia vetusta gulosa (Boisd.) (=*Hemerocampa*)	Leaves	See ceanothus
Nymphalidae		
Nymphalis antiopa (Linn.)	Leaves	Weed 1899
Saturniidae		
Hemileuca maia (Drury)	Leaves	
nevadensis Stretch	Leaves	
Tortricidae		
Archips cerasivorana Fitch	Leaves	
ACARINA		
Eriophyidae		
Aculops tetanothrix (Nalepa)	Leaves	
Aculops n.sp.	Leaves (Alaska)	

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ACKNOWLEDGMENTS

I owe my interest in insects on browse plants to Dr. W. F. Barr, University of Idaho, and to my brother, R. L. Furniss, Portland, Oregon. Their stimulation has led to many hours of observing, photographing, and collecting afield.

Help in collecting from distant places was given by P. F. Stickney, R. B. Ferguson, A. P. Plummer, and J. V. Basile of the Intermountain Forest and Range Experiment Station. Others who helped collect insects or who provided information were Dr. R. C. Bechtel, Nevada Department of Agriculture, and T. A. Leege and L. E. Trout, Idaho Department of Fish and Game. Information on particular groups of insects was provided as follows:

Saturniidae, Dr. D. W. Davis, Utah State University;
Buprestidae and Chrysomelidae, Dr. W. F. Barr, University of Idaho;
Cerambycidae, Dr. R. L. Penrose, Oregon Department of Agriculture;
Sternochetus, Dr. J. W. E. Harris, Canada Department of Fisheries and Forestry.

Identification of specimens was provided mainly by taxonomists at the U.S. National Museum. Special assistance was received from the following taxonomists:

Dr. D. J. Williams, British Museum *(Lecanium)*;
Dr. J. A. Powell, University of California *(Ethmia, Hemerocampa)*;
Dr. R. W. Hodges, USDA Insect Identification and Parasite Introduction Research Branch *(Filatima, Gelechia)*;
Dr. F. H. Rindge, American Museum of Natural History *(Anacamptodes)*;
Dr. F. W. Stehr, Michigan State University *(Malacosoma)*; and
Mr. H. H. Keifer, California Department of Agriculture *(Aceria)*.

The accuracy of scientific names and classification was checked by Dr. R. C. Froeschner of the U.S. National Museum; and by the following staff members of the USDA Insect Identification Branch:

Dr. D. M. Anderson,
Dr. E. W. Baker,
Dr. B. D. Burks,
Dr. R. J. Gagne,
Dr. A. B. Gurney,
Dr. J. L. Herring,
Dr. R. W. Hodges,
Dr. J. P. Kramer,
Dr. D. R. Miller,
Louise M. Russell,
Dr. D. R. Smith,
Mr. G. C. Steyskal,
Dr. E. L. Todd,
Mr. G. B. Vogt, and,
Rose E. Warner.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1972 - 780 - 702/92 REGION I

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-156

February 1972

PRELIMINARY ANNOTATED LIST OF DISEASES OF SHRUBS ON WESTERN GAME RANGES

R. G. Krebill[1]

ABSTRACT

*Presents a list of diseases of serviceberry (*Amelanchier *spp.), sagebrush (*Artemisia *spp.), ceanothus (*Ceanothus *spp.), mountain mahogany (*Cercocarpus *spp.), chokecherry (*Prunus virginiana*), bitterbrush (*Purshia tridentata*), and willows (*Salix *spp.). Diseases caused by fungi, bacteria, viruses, and parasitic plants, as well as common physiogenic problems such as winter injury, are included.*

This annotated checklist was compiled to establish a basis for beginning evaluation of the effects of plant diseases on shrubs browsed by big game in Western United States.[2] Included in this list are several of the key shrubs that enhance the carrying capacities of major game winter ranges. Information--unless otherwise cited--was derived from the "Index of Plant Diseases in the United States" (USDA Agr. Res. Serv. 1960), the "Host Fungus Index of the Pacific Northwest" (Shaw 1958), and "Mycoflora Saximontanensis Exsiccata" (Solheim 1934-1970). Only those organisms known by the author to be pathogenic to browse hosts are included in this list. Where possible, diseases are arranged alphabetically by cause or causal organism; common names such as "damping-off" are used when the cause is not clearly known.

This is intended as a provisional working list of browse plant diseases, and the author invites supplemental information for use in a future more inclusive treatment.

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[1]Plant Pathologist, stationed in Logan, Utah 84321, at the Forestry Sciences Laboratory, maintained in cooperation with Utah State University.
[2]Excluding Alaska, Hawaii, and Texas.

Air pollution - highly sensitive to SO_2 and fluoride (Anderson 1966; Carlson & Dewey 1971; and Shaw 1952); a problem only locally in the West.

Apiosporina collinsii (Schw.) Hoehn. - witches'-brooms and stem cankers; widespread through Rocky Mountains. Has a *Cladosporium* imperfect stage.

Cylindrosporium aroniae Sacc. - leaf spot in Montana and Washington.

Damping-off - considered a problem with seedling survival in a greenhouse (Peterson 1953).

Erwinia amylovora (Burr.) Winslow et al. - fireblight, a shoot die-back caused by a bacterium; known in Montana, but possibly widespread throughout the West.

Erysiphe polygoni DC. ex Mérat - powdery mildew on leaves and twigs in northern Rocky Mountains.

Fabraea maculata Atk. - leaf blight; locally common throughout much of the West. Has an *Entomosporium* imperfect stage.

Gymnosporangium clavariiforme (Pers.)DC. - rust of leaves, fruits, and sometimes twigs. Common in Rocky Mountains.

G. clavipes (Cke. & Pk.) Cke. & Pk. - rust of fruits and twigs; local in northern Rocky Mountains.

G. cupressi Long & Goodding - rust of leaves; local in California (Peterson 1968) and Arizona.

G. harknessianum Kern ex Arth. - rust chiefly on fruits and stems; in Cascades and Sierra Nevada Mountains.

G. inconspicuum Kern - rust chiefly on fruits; common, especially in Great Basin (Peterson 1967) and southeastward to New Mexico and Arizona.

G. kernianum Bethel - rust of fruits and leaves; common from Arizona and New Mexico to Idaho and Oregon (Peterson 1967).

G. libocedri (P. Henn.) Kern - rust of leaves and fruits; common to abundant in Cascades and northern Sierra Nevada.

G. nelsonii Arth. - rust of leaves and fruits; common throughout Rocky Mountains.

G. nidus-avis Thaxt. - rust of leaves, stems, and fruits; common to abundant in Rocky Mountains.

Lophodermium hysterioides (Pers.) Sacc. - leaf spot in northern Rocky Mountains.

Nectria cinnabarina Tode ex Fr. - stem canker in Idaho and Oregon.

Phyllactinia guttata (Fr.) Lév. - powdery mildew of foliage in Colorado and Washington.

Phyllosticta innumerabilis Pk. - leaf spot in Montana and North Dakota.

Sclerotinia gregaria Dana - leaf and fruit blight; local in Washington and Colorado.

Taphrina amelanchieri Mix. - witches'-broom; in California.

Tympanis amelanchieris Groves - on twigs in Idaho.

ARTEMISIA[3]

Cylindrosporium artemisiae Dearn. & Barth. - leaf spot in Washington.

Eyrsiphe cichoracearum DC. ex Mérat - powdery mildew of foliage; widespread in the West.

Fomes annosus (Fr.) Cke. - root rot of big sagebrush in California (Smith, Bega, and Tarry 1966).

Phyllosticta raui (Pk.) Dearn. & House - leaf spot in northern Rocky Mountains.

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[3]Disease list refers only to species of *Artemisia* that are woody shrubs.

Puccinia atrofusca (Dudl. & Thomp.) Holw. - leaf rust; common on many sagebrush species in the West.

P. millefolii Fckl. - leaf rust; occurs on some of the semishrubby sagebrushes in the West.

P. tanaceti DC. - leaf rust; the most common rust on many species of sagebrush including big sagebrush.

Sclerotium sp. - stem blight in Oregon.

Septoria artemisiae Pass. - leaf spot in Washington.

Syncarpella tumefaciens (Ell. & Harkn.) Th. & Syd. - black knot stem gall in inland West.

Uromyces oblongisporus Ell. & Ev. - leaf rust known locally in Wyoming on big sagebrush.

CEANOTHUS

Agrobacterium tumefaciens (E. F. Sm. & Town.) Conn - bacterial crown gall in Washington.

Armillaria mellea (Vahl ex Fr.) Quél. - root rot induced dieback; widespread in Inland Empire (Tarry and Shaw 1966) and California.

Cercospora ceanothi Kell. & Swing. - leaf spot in Kansas.

Cylindrosporium ceanothi Ell. & Ev. - leaf spot in Pacific Coast States.

Damping-off - a common seedling disease (Peterson 1953; USDA Forest Serv. 1948).

Eutypa armeniacae Hansf. & Carter - top dieback in ornamental wild lilacs in California. Has a *Cytosporina* imperfect stage (Moller, Ramos, and Hildreth 1971).

Microsphaera penicillata (Wallr. ex Fr.) Lév. - powdery mildew of foliage in Idaho and Washington.

Puccinia tripsaci Diet. & Holw. - leaf rust in Plains States. Also found on Gramineae alternate hosts west to New Mexico.

Septoria ceanothi Dearn. - leaf spot in Idaho.

Winter injury - foliage dieback, periodically widespread in inland West.

CERCOCARPUS

Damping-off - heavy seedling losses may occur on alkaline soils (USDA Forest Serv. 1948).

Fomes annosus (Fr.) Cke. - root rot in northeastern California (Tegethoff[4]).

Gloeosporium cercocarpi Ell. & Ev. - leaf spot in California.

Septogloeum cercocarpi Bonar - leaf spot in California. A somewhat similar leaf spot from Nevada to Washington is under study at the Forestry Sciences Laboratory, Logan, Utah, and awaiting positive identification.

Sphaceloma cercocarpi Bitan. and Jenkins - leaf anthracnose in California.

PRUNUS VIRGINIANA L.

Air pollution - of intermediate sensitivity to SO_2 and fluoride (Anderson 1966; Carlson and Dewey 1971; and Shaw 1952); a local problem in the West.

Cercospora circumscissa Sacc. - leaf spot from Montana to Kansas.

Coccomyces lutescens Higgins - shot-hole leaf spot; general throughout the West.

Cylindrosporium nuttallii (Harkn.) Dearn. - leaf spot in Oregon.

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[4]Personal communication from A. C. Tegethoff, Plant Pathologist, USDA Forest Serv., R-4, Ogden, Utah.

Damping-off - apparent resistance was high in a greenhouse test in loam soil (Peterson 1953).

Dibotryon morbosum (Schw.) Th. & Syd. - black knot canker; general and abundant in the West. Has a *Cladosporium* imperfect stage.

Eutypa armeniacae Hansf. & Carter - a canker disease in California (English and Davis 1965). Has an imperfect stage of *Cytosporina*, and is an important dieback disease of apricot.

Lophodermina prunicola Tehon - tar spot of leaves in Colorado.

Mycosphaerella cerasella Aderh. - leaf spot in Kansas.

Nectria cinnabarina Tode ex Fr. - stem canker; widespread in the West.

Phyllactinia guttata (Fr.) Lév. - powdery mildew in Washington.

Phyllosticta circumscissa Cke. - leaf spot in Kansas and Washington.

P. virginiana (Ell. & Halst.) Ell. & Ev. - leaf blotch in Kansas and Montana.

Podosphaera clandestina (Wallr. ex Fr.) Lév. - powdery mildew of foliage in northern Rocky Mountains.

Sclerotinia demissa Dana - shoot and fruit blight; widespread in Rocky Mountains.

Taphrina confusa (Atk.) Gies. - causes hypertrophy of leaves, fruits, and young stems. Widespread in the West.

Tranzschelia pruni-spinosae (Pers.) Diet. - leaf rust in Nebraska, and known west to California on Ranuculaceae alternate hosts (Arthur 1934).

Twisted leaf virus disease of cherry - chokecherry is a symptomless carrier of this virus at the border between north-central Washington and British Columbia (Lott and Keane 1960).

Valsa spp. and their imperfect stage *Cytospora* - on twigs possibly as canker diseases from Washington to Kansas.

Western X-disease virus - widespread in Rocky Mountains and Pacific Northwest and of major importance to stone fruit industry (Reeves and others 1951). A mycoplasma may be involved in inciting this disease (Huang and Nyland 1970).

PURSHIA TRIDENTATA (PURSH) DC.

Armillaria mellea (Vahl ex Fr.) Quél. - root rot in central Idaho, northern California, and possibly southern Oregon (Kimmey[5]).

Cuscuta sp. - dodder; a parasitic plant on bitterbrush seedlings in southern Idaho (Tegethoff[6]).

Damping-off - a common problem in establishing bitterbrush plants from seeds in the West (Brown and Martinsen 1959; Holmgren 1956; and Peterson 1953). *Rhizoctonia solani* Kühn and *Pythium ultimum* Trow. have been shown experimentally to cause damping-off in bitterbrush (Nord 1965).

Dieback - bitterbrush is declining on 30,000 acres in northeastern California and adjacent Oregon from an unknown cause (Calif. Forest Pest Control Action Counc. 1970).

Diplodia sp. - associated with a root-stem canker in northeastern California (Nord 1965). Also see *Fusarium* sp.

Drought - in 1934, a drought seriously set back natural stands of bitterbrush in southeastern Idaho (Pechanec, Pickford, and Stewart 1937).

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[5]Personal communication with Dr. J. W. Kimmey, retired Plant Pathologist, USDA Forest Service, now in Westport, Washington.

[6]See footnote 4.

Fomes annosus (Fr.) Cke. - root rot in Idaho (specimen K-868 at Logan FSL).

Frost injury - a spring frost in 1964 caused extensive dieback over about 22,000 acres in eastern California (Smith, Scharpf, and Schneegas 1965).

Fusarium sp. - isolated at Logan FSL from roots of dying bitterbrush from an Idaho planting area. *Fusarium* sp. was also associated with the *Diplodia* sp. of the root-stem canker described by Nord (1965).

SALIX

Air pollution - willows in Pacific Northwest are fairly sensitive to SO_2 (Shaw 1952).

Armillaria mellea (Vahl ex Fr.) Quél. - root rot in California and Washington.

Ascochyta salicis Bonar - leaf spot in California.

Black Hills mortality - cause not clarified, possibly several contributing factors (Froiland 1962).

Ciborinia foliicola (Cash and Davidson) Whetzel - Black rib disease on leaves in Colorado (Davidson and Cash 1933).

Cryptodiaporthe salicina (Curr.) Wehm. - twig and branch canker in Great Plains and Pacific Coast States. Has an imperfect stage of *Discella carbonacea* (Fr.) Berk. & Br.

Cryptomyces maximus (Fr.) Rehm. - bark blister canker in New Mexico, Utah, and Wyoming (specimen K-871 at Logan FSL).

Cryptosporium sp. - branch canker in California.

Cuscuta sp. - dodder (a flowering plant) parasitizes willow in Utah and Washington.

Cylindrosporium salicinum (Pk.) Dearn. - leaf spot in Colorado and Pacific Northwest.

Dothiora polyspora Shear and Davidson - twig canker and dieback in Colorado.

Dothiorella gregaria Sacc. - black canker in California.

Dothiorella sp. - canker in North Dakota.

Gloeosporium boreale Ell. & Ev. - leaf spot in Wyoming and Arizona.

Helicotylenchus anhelicus Sher. - root nematode in California (Ruehle 1967).

Hemicycliophora hesperis Raski - root nematode in California (Ruehle 1967).

Herbicides - willows are quite sensitive (Lyon and Mueggler 1968; and Ryker 1970).

Marssonina apicalis (Ell. & Ev.) Magn. - leaf spot in California and Wyoming.

M. kriegeriana (Bres.) Magn. - leaf spot in California and Wyoming.

M. rubiginosa (Ell. & Ev.) Magn. - leaf spot in Idaho.

M. sp. - leaf and twig blight in Pacific Northwest.

Melampsora epitea Thuem. - rust; abundant on foliage of willows throughout the West.

M. paradoxa Diet. & Holw. - rust; abundant on foliage of willows throughout the West.

Melanconium sp. - twig canker in Colorado.

Meloidogyne sp. - root knot nematode in Arizona (Ruehle 1967).

Nectria spp. - canker of stems in New Mexico and Pacific Northwest.

Ocellaria ocellata (Pers. ex Fr.) Schroet. - stem canker in Colorado and North Dakota.

Phomopsis salicina (West.) Died. - twig canker in Washington.

Phoradendron spp. - mistletoes are common parasites on stems of willows in the Southwest.

Phyllactinia guttata (Fr.) Lév. - Powdery mildew of foliage in Washington.

Phyllosticta apicalis J. J. Davis - leaf spot in Great Plains.

P. salicicola Thuem. - leaf spot in Idaho.

P. salicis Kell. & Swingle - leaf spot in Kansas.

Pratylenchus vulnus Allen & Jensen - root nematode in California (Ruehle 1967).

Pseudopeziza salicis (Tul.) Poteb. - leaf spot and twig blight in Oregon and Washington; has an imperfect stage of *Gloeosporium salicis* West.

Ramularia rosea (Fckl.) Sacc. - leaf spot in Rocky Mountains.

Rhytisma salicinum (Pers.) Fr. - tar spot on leaves; common in Great Plains, Rocky Mountains, and Pacific Northwest.

Sclerophoma salicis Died. - twig blight in California.

Septogloeum maculans Harkn. - leaf spot in California and Montana.

S. salicis-fendlerianae Dearn. & Barth. - leaf spot in Rocky Mountains.

Septoria salicicola (Fr.) Sacc. - leaf spot in Oregon.

S. sp. - leaf spot in Idaho and Oregon.

Sphaceloma murrayae Jenkins and Grodsinsky - gray scab of foliage in Pacific Coast States.

Taphrina populi-salicis Mix - yellow leaf blister in California.

Trichodorus californicus Allen - root nematode in California (Ruehle 1967).

Uncinula salicis (DC. ex Mérat) Wint. - powdery mildew of foliage; common throughout the West.

Valsa spp. - twig and branch canker with *Cytospora* imperfect stage. Common throughout the West.

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☆ U. S. GOVERNMENT PRINTING OFFICE 1972 - 780 - 831/120 REGION

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-157

March 1972

STATION PUBLICATIONS IN FOREST GENETICS AND RELATED FIELDS[1]

R. T. Bingham[2]

ABSTRACT

Lists 123 Station and Station-connected publications in forest genetics, tree breeding, and related fields, dating from 1921. Revises and updates Roberts, V., USDA Forest Serv. Res. Note INT-48, 1966. Over one-half of the publications are concerned with white pines (principally Pinus monticola*), and over one-third deal with various aspects of white pine blister rust resistance. Other species receiving more than minor attention are* Pinus ponderosa, P. contorta *and* Pseudotsuga menziesii.

ANDRESEN, J. W., and R. J. STEINHOFF
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1967. Phenotypic variation associated with elevation in western white pine. Forest Sci. 13(4): 357-364.

**BARNES, BURTON V.
1969. Effects of thinning and fertilizing on production of western white pine seed. USDA Forest Serv. Res. Pap. INT-58, 14 p.

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[1]Single asterisk (*) indicates that reprints are available at Forestry Sciences Laboratory, P.O. Box 469, Moscow, Idaho 83843; (**) double asterisks indicate that reprints are available at Intermountain Forest and Range Experiment Station, 507-25th St., Ogden, Utah 84401.

[2]Principal Plant Geneticist, USDA Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, which is maintained in cooperation with the University of Idaho.

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1962. Juvenile performance of hybrids between western and eastern white pine. USDA Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Note 104, 7 p.

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1963. Cultural treatments stimulate growth of western white pine seedlings. USDA Forest Serv. Res. Note INT-3, 8 p.

*BARNES, BURTON V., and R. T. BINGHAM
1963. Flower induction and stimulation in western white pine. USDA Forest Serv. Res. Pap. INT-2, 10 p.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1972-781-539/195 REGI

Research Note
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-158

April 1972

STEM DEFORMITIES IN YOUNG TREES CAUSED BY SNOWPACK AND ITS MOVEMENT

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ABSTRACT

Snow movement in deep snowpack zones of steep mountainous country in northern Idaho contributes significantly to the frequency and severity of a variety of stem deformities in young conifer stands. This note defines six classes of deformities of which butt sweep was the most frequent and dog leg and stem failure the most injurious. All deformities except three originated within 5 feet of ground line. Much of the tree length on affected trees was deformed; as trees increased in height, increasingly higher percentages had two or more deformities.

While marking leave trees in one of our experimental thinning areas, we frequently found deformed stems in all tree species. Up to 74 percent of the leave trees on some of the 1-acre test plots were deformed. As a result, we installed study plots to assess severity and frequency of these deformities.

AREA DESCRIPTION AND DATA COLLECTION

The study area is situated within a series of clearcuts involving more than 2,000 acres on the Coeur d'Alene National Forest in northern Idaho (fig. 1). Because of its location (between 3,660 and 4,560 feet elevation on a north exposure) and the fact that the prevailing winds during the winter are from the southwest, the area accumulates snow early in the season, which frequently remains until late May or early June. The slope ranges between 44 and 66 percent; the average is 55 percent.

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[1]Respectively, Principal Plant Pathologist, Research Forester, and Biological Technician, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

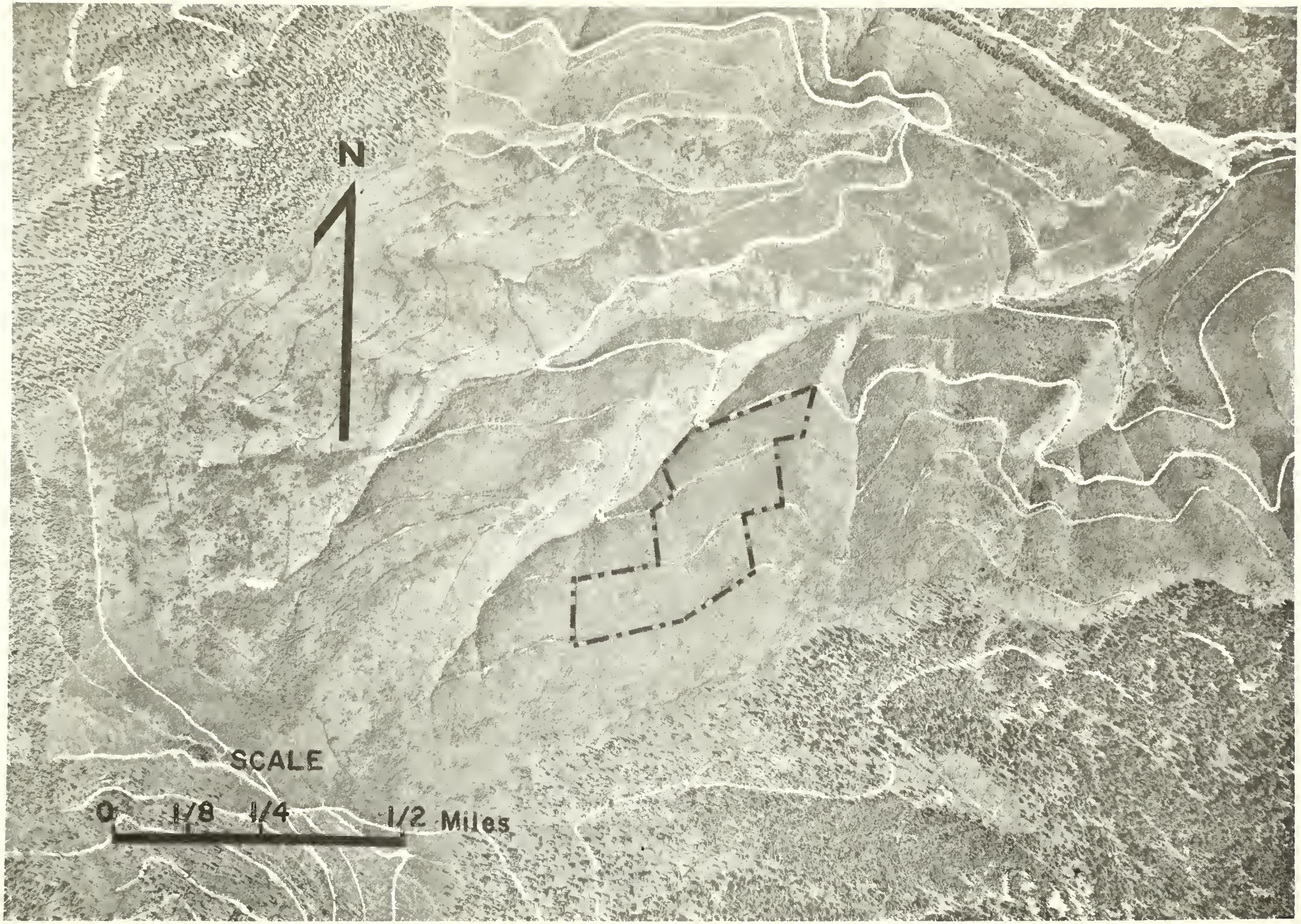

Figure 1.--Aerial photo of a portion of a large clearcut unit in Potter Creek, Coeur d'Alene National Forest. Study area is delineated by a dashed line.

Following logging, most of the snags were felled and the area was burned. Two years later (in 1959), western white pine 2-2 stock was planted at about an 8- by 8-foot spacing. Subsequent natural regeneration resulted in an overstocked stand (nearly 2,560 stems/acre) of the following species: alpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), Engelmann spruce (*Picea engelmanni* Parry), western larch (*Larix occidentalis* Nutt.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western white pine (*Pinus monticola* Dougl.).

The study area's habitat type is *Tsuga heterophylla-Pachistima myrsinites* (Daubenmire and Daubenmire 1968). Its estimated site index is about 60; no data were available from the previous stand. Trees now range in height from 1 to 20.5 feet; the average tree is between 4 and 4.5 feet tall.

Within the study area, which comprises approximately 30 acres (fig. 1), we established 48 plots (each 1/300 acre in size). A deformed tree served as the center of each of these 48 plots. All conifers on these plots were recorded according to (a) species, (b) height to the nearest one-half foot, and (c) diameter at breast height (d.b.h.) by 1-inch classes; these were grouped within the following classifications:

Class 1. Not deformed--stem either not deformed or not deviating more than 6 inches from an axis that passes through the root collar perpendicular to the contour.

Class 2. Butt sweep--a deviation of more than 6 inches from the vertical axis originating at the root collar. Usually, the sweep extends between about 2 or 3 feet from the ground and, above it, the stem is vertical (fig. 2).

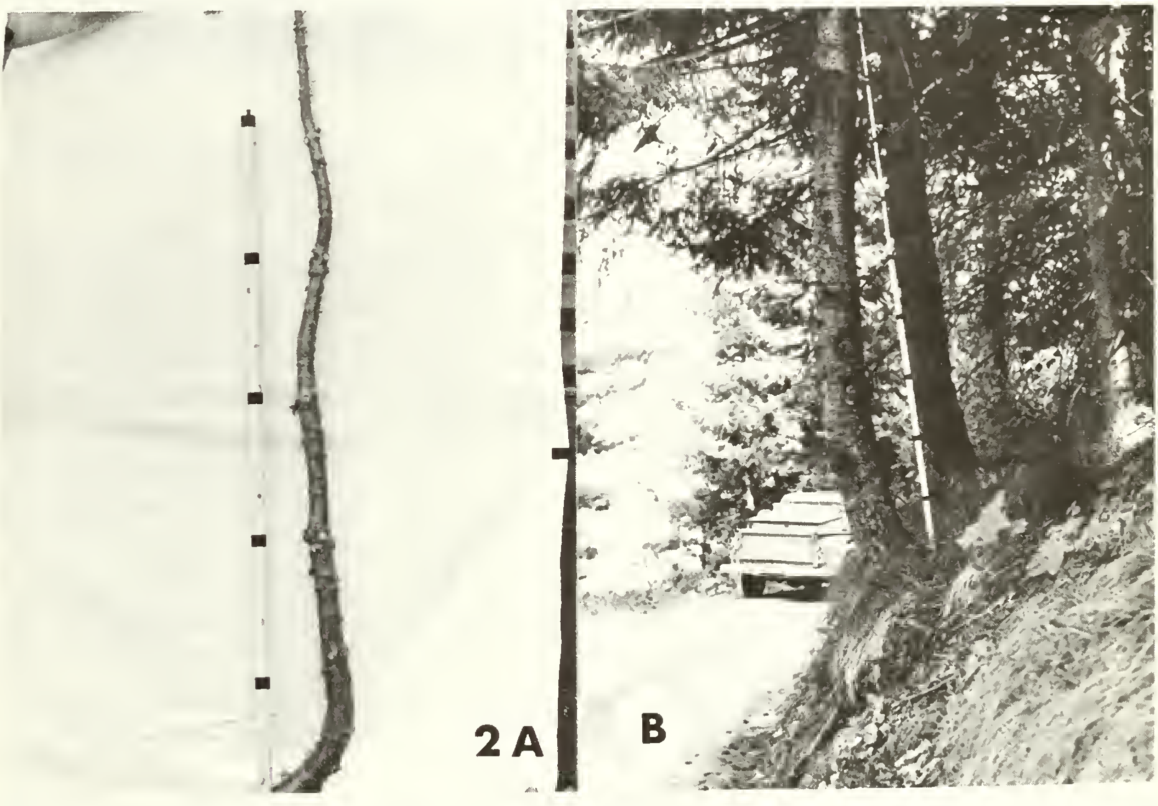

Figure 2.--Butt sweep: (Black marks on the pole are at 1-foot intervals for figures 2-6.) A, An 8-year-old grand fir having moderate sweep to 1.5 feet and slight stem sweep from 3.5 to 6.0 feet; B, a ±40-year-old Douglas-fir having moderate sweep to 2.5-3.0 feet.

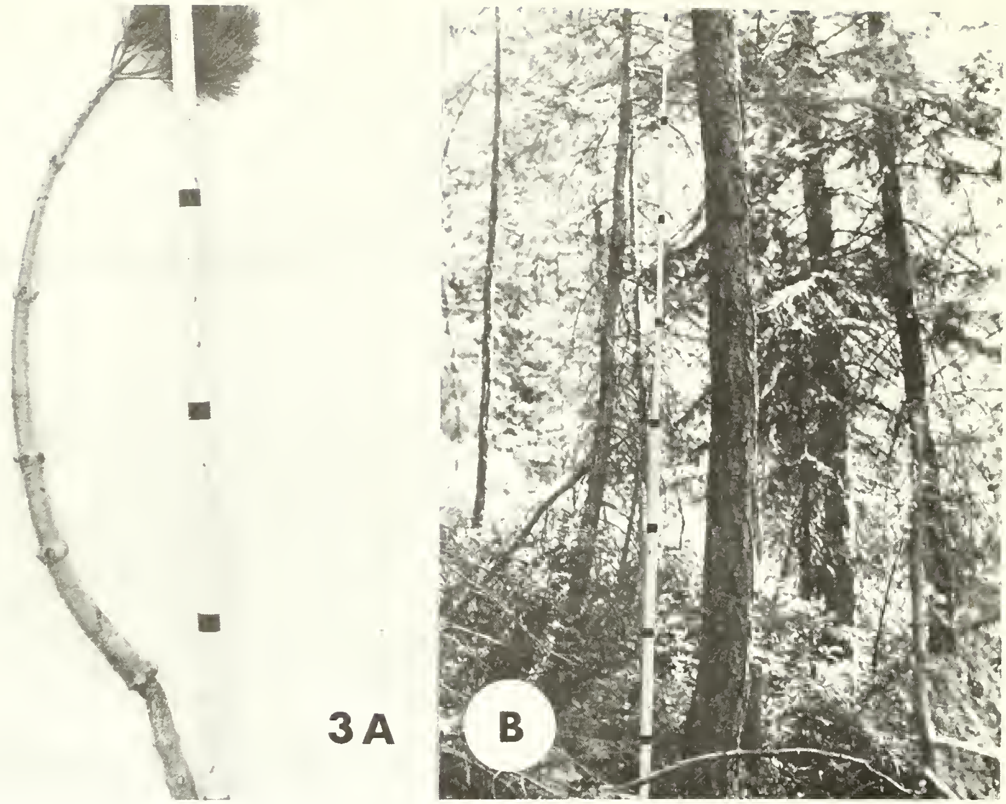

Figure 3.--Stem sweep: A, A 10-year-old western white pine having sweep originating at a blister rust canker at 0.5 foot; B, a ±40-year-old western larch having sweep to 11 feet.

Class 3. Stem sweep--same as in Class 2--the sweep assumes a gentle curve in one plane, originates at any point along the stem, and contains a minimum segment of 2 feet before returning to the vertical (fig. 3).

Class 4. Dog leg--a sharp curve departure of more than 6 inches from the perpendicular axis; usually not more than 2 feet long (fig. 4). Stem failure frequently occurs at the point of maximum stem departure.

Class 5. S-curve--similar to Class 3 but one curve is superimposed above another in reverse to create one or more S-shaped curves in the stem (fig. 5). Frequently, these curves are not associated with stem failure and might be in one to several planes.

Class 6. Stem failure--any form of failure from a simple buckling to a complete separation of both xylem and phloem elements (fig. 6). It most frequently is associated with a curve deformity.

Class 7. Branch pull--branch either completely pulled from the stem or pulled sufficiently so that all of it died.

In addition to those found in the study area, similar deformities on surviving trees were observed in a number of stands between 40 and 80 years old on the same National Forest. These stands also are located in mountainous, deep-snowpack country.

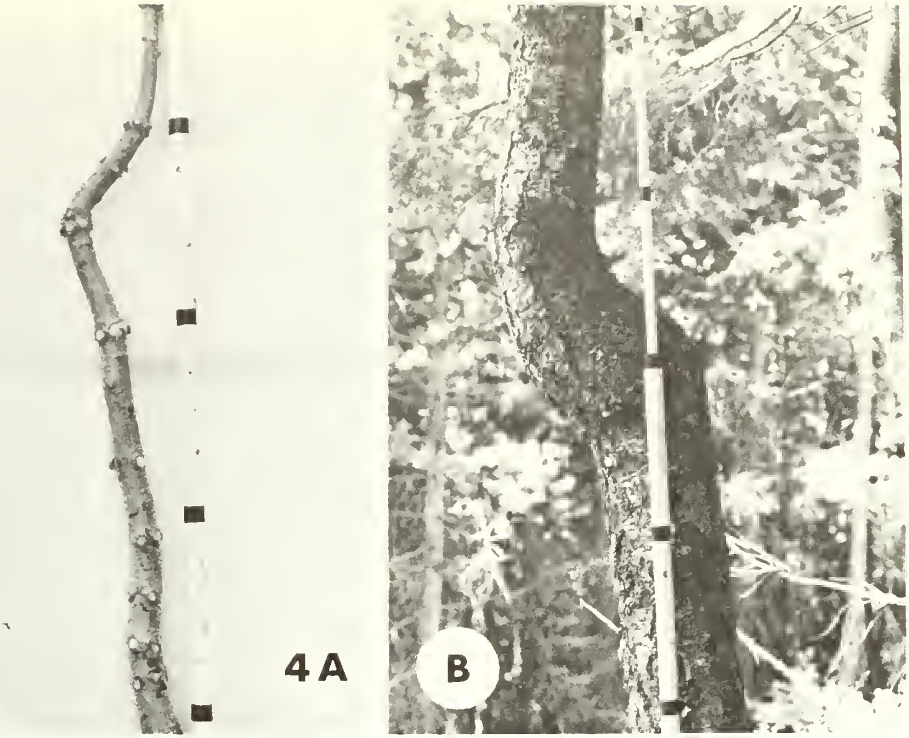

Figure 4.--Dog leg: A, an 11-year-old grand fir having deformity at 3 to 4 feet. A stem failure occurs at 3.5 feet. B, ±45-year-old Douglas-fir having dog leg deformity (and apparently a stem failure).

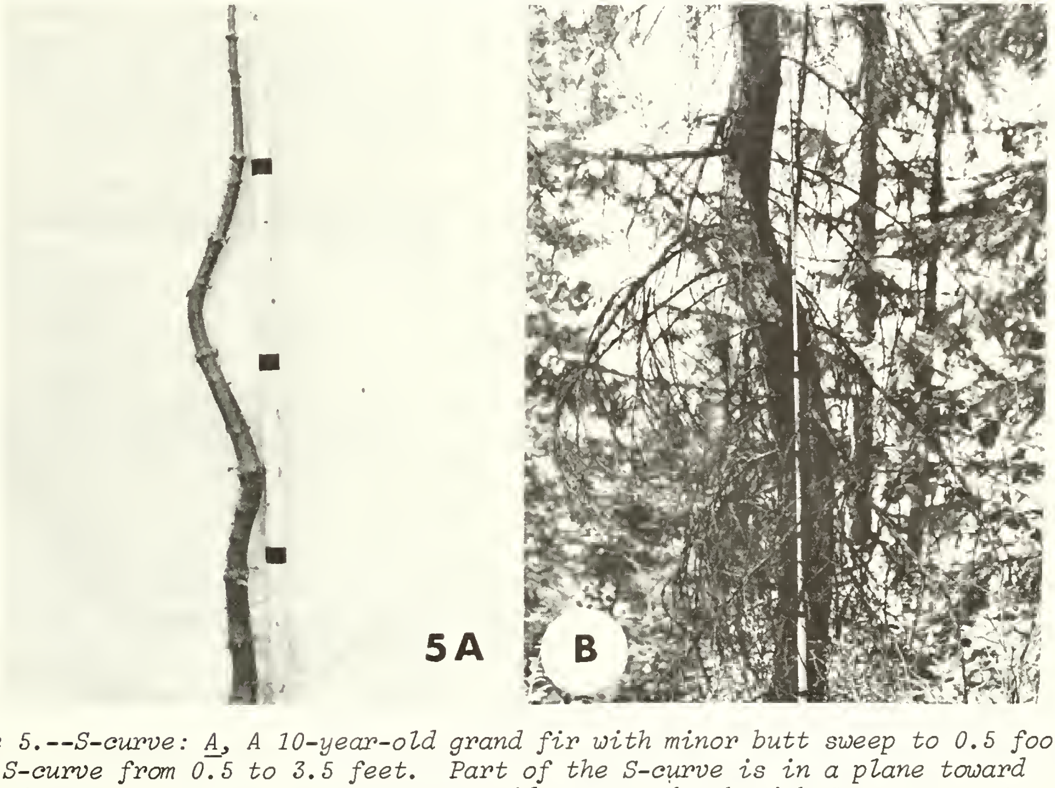

Figure 5.--S-curve: A, A 10-year-old grand fir with minor butt sweep to 0.5 foot and S-curve from 0.5 to 3.5 feet. Part of the S-curve is in a plane toward the viewer at 1.5 feet; B, a ±45-year-old western larch with S-curve to 14 feet above a stem sweep which went from 0 to 18 feet.

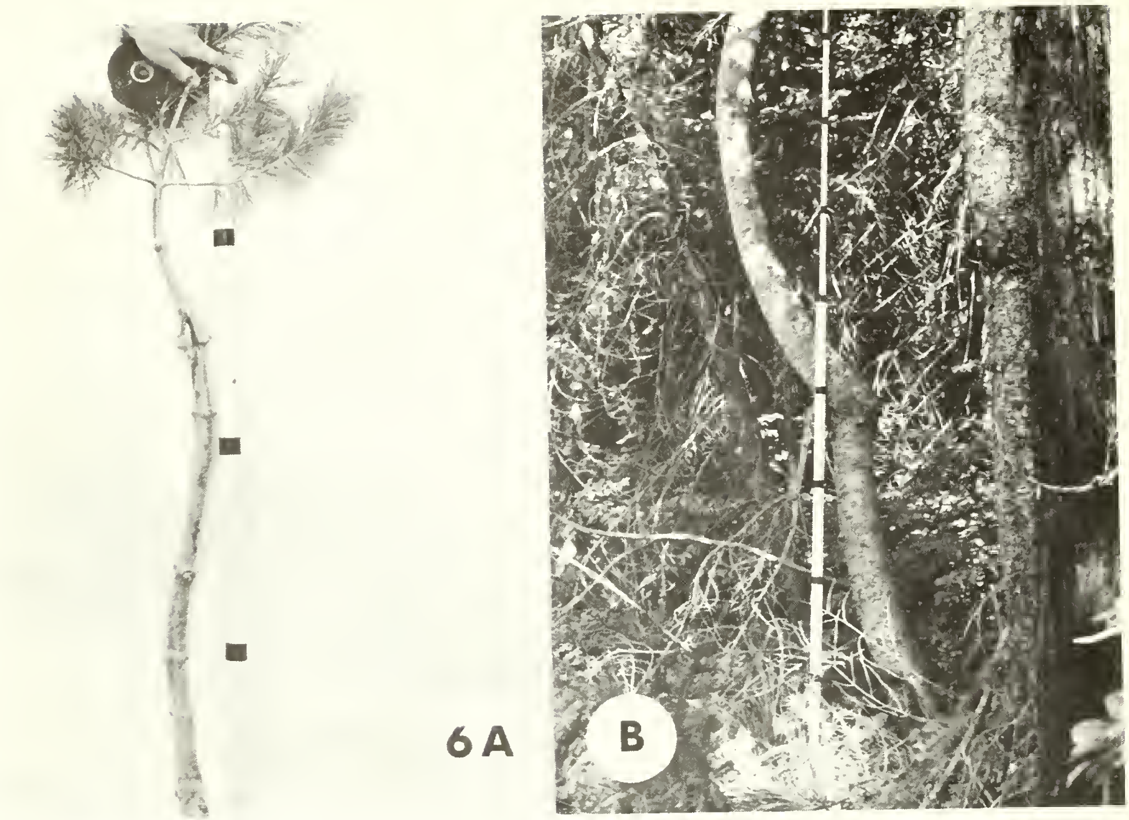

Figure 6.--Stem failure: A, A 12-year-old western white pine with stem failure at 2.5 feet, plus butt sweep and S-curve. Failures were more frequently of the type of buckling shown in figure 4-A; B, ±45-year-old western white pine with stem failure at 4 feet and stem sweep to above 11 feet.

RESULTS

Of the 410 trees on all 48 plots, 24 percent were not deformed (Class 1). Of these, 73 percent were less than 2.5 feet tall. There was an average of slightly more than one deformity per tree; as trees increased in height, increasingly higher percentages of them had two or more deformities (fig. 7).

Among 463 deformities recorded, butt sweep (Class 2) was the most frequent (40 percent). The remainder, broken down by class and ranked according to frequency of occurrence, were as follows: Class 5, 22 percent; Class 3, 15 percent; Class 6, 9 percent; Class 4, 7 percent; Class 7, 5 percent; and miscellaneous deformities, 2 percent. In all but one of the trees having Class 5 deformities, the S-curve involved more than 50 percent of the tree height; in 73 percent of these trees, more than 75 percent of the tree height was affected. Stem sweep (Class 3) usually encompassed most of the stem: in 71 percent of the trees having stem sweep, the deformity originated at ground line. In 69 percent of these trees, furthermore, the deformity covered the entire length of the stem.

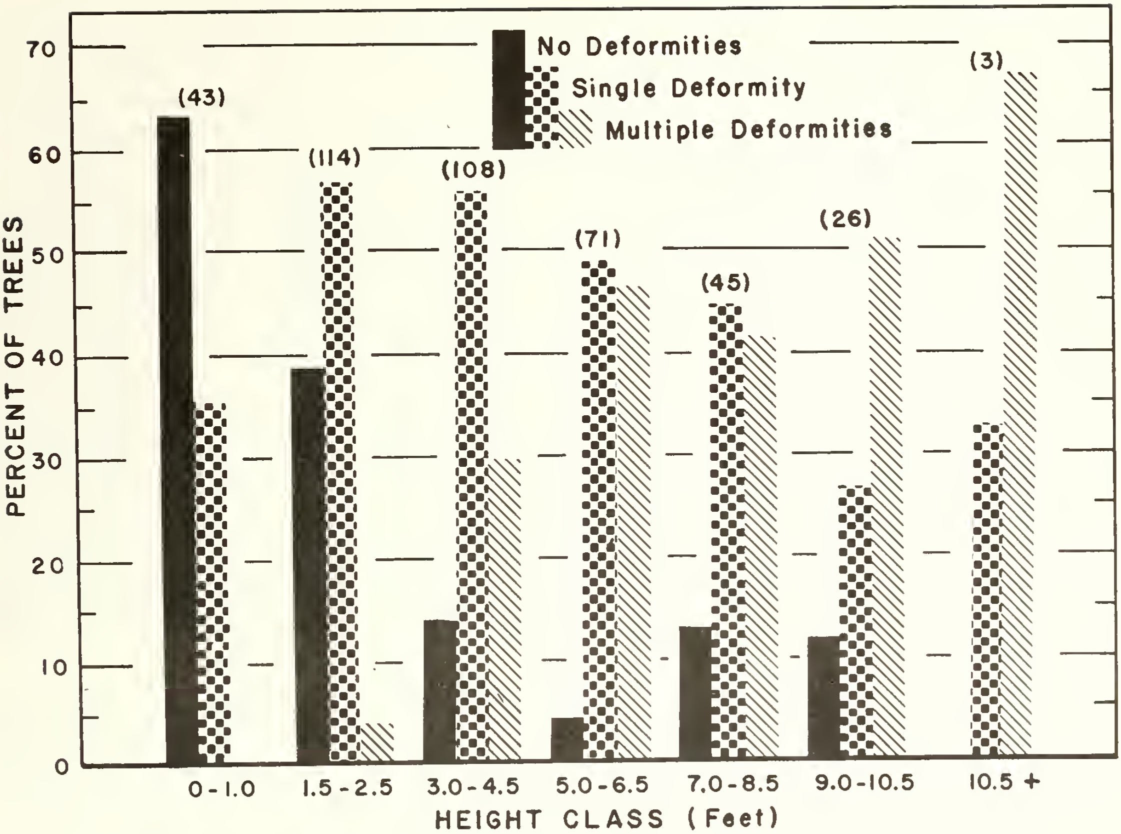

Figure 7.--Percentage of trees within height classes by frequency of stem deformity. Numbers of trees in each height class are shown in parentheses.

All the deformities, except those in the miscellaneous group, appeared to be the result of snowpack movement or snow load. Although we do not have snow records for the study site, snow data from the Copper Ridge snow course (located about 9 airline miles to the southwest at ±4,800-foot elevation on a timbered ridge along a roadway) gave only an approximation (likely an underestimate) of conditions at the study site. For the years 1959-70, maximum snow depth at Copper Ridge ranged from 3.0 to 8.8 feet. This depth is significant when one relates it to the average height, 4 to 4.5 feet, for the trees found on the study area in 1970. Thus, it becomes apparent that sample trees undoubtedly had been subject to the action of snow movement for some period each year during their lives.

Stem curvature deformities, with few exceptions, were alined perpendicular to the contour--in the downhill direction of snow movement. All but three of the deformities originated within 5 feet of the ground line. There were 75 serious deformities--all in Class 4 (dog leg) and Class 6 (stem failure) and all terminating within 7 feet of the ground: 13 percent below 1.5 feet; 63 percent between 1.5 and 3.5 feet; and the remainder between 3.5 and 7 feet.

Although some species were not frequently represented in all height or deformity classes, all species were equally susceptible to deformities. On the average, western larch and western white pine trees were much taller and larger (at d.b.h.) than were the other species. Consequently, many trees of these two species are not likely to suffer additional deformity.

DISCUSSION

Relatively few stands at high elevations in northern Idaho are free of butt sweep (fig. 2-B). Although this deformity has many causes (such as growth of the tree from beneath logs, snags rolling against the tree base, etc.), the most frequent is movement of snow during the early life of the tree (Daubenmire 1959, p. 97). Our observations suggest that the frequency and severity of butt sweep in deep-snowpack zones on the Coeur d'Alene National Forest increase along with slope (particularly as orientation changes to the north) and with cleanness of the regeneration burn. However, in the study area, the plots were homogenous with respect to percentage of deformed trees. Slopes were steep throughout. Neither steepness nor slope position contributed significantly to between-plot variation in deformities; this was analyzed using a weighted regression method (Duncan and Walser 1966). Although the effect of slope on snow movement is difficult to assess (in der Gand 1968), most slope gradients were probably more than sufficient to initiate downhill movement under the snow loads present in the area.

Except for the S-curve deformity (fig. 5B), other deformities in older stands followed much the same frequency pattern as noted in the young stands. We found very little external evidence that this S-curve deformity persisted in trees 40 years of age, or older. Thus, while we might have failed to detect much of it in older stands, either it was a rare deformity when such stands were young or the trees outgrow it. While only long-term studies can reveal the true significance of S-curve deformity, it is frequent (22 percent of all deformities in this study) in the young stands. In older stands, it probably occurs as a hidden deformity; thus it would only show up when the tree is cut into lumber and seasoned. This would be a significant defect in boards, especially on those cut from trees harvested at up to 12 inches d.b.h.

Snow creep (movement inside the snow layers) and/or snow gliding (movement of entire snowpack over the ground[2] did occur in similar areas.[3] Our data clearly reflect both types of movement. The random distribution throughout the plots of nondeformed trees, as well as that of trees having dog leg or stem failure deformities suggests that mass snow sliding didn't occur within the study area. However, local gliding was prevalent throughout; this was evidenced by the high frequency of butt sweep. As in der Gand (1968) observed at Matte-Frauenkirch, we also found that deterring objects (i.e., snags, low stumps, or some of the larger trees) had only a proximate deterring influence on snow movement because deformed trees were found within several feet of such objects.

Although density and height of tall brush species (e.g., alder, willow, and mountain maple) varied throughout the unit, such factors did not significantly alter the type or frequency of deformities. Either we failed to record the necessary detail about brush on the plots, or its impeding effect on snow movement is limited. The latter is more probable because data on S-curve, stem failure, and dog leg deformities suggest that a significant amount of snow creep occurred. Also, some brush species, such as alder, tend to lie down under a snow cover; thus, they fail to deter snow creep.

Curve deformities result from the natural response of the tree as it resumes its upright growth after its stem has been bent from the vertical. Although the series of events leading to the various curve types has not been documented, our observations

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[2]in der Gand (1968), the Forest Service translation of which mistakenly terms "snow gliding" as "snow sliding."

[3]Unpublished data on snow movement effects on snowmelt lysimeters at the Priest River Experimental Forest in northern Idaho. On file at Forestry Sciences Laboratory, Moscow, Idaho.

suggest the following: dog leg apparently results from the snow creep of a single year and S-curve from at least two seasons of snow creep fairly close together. In both, snow has moved in layers one or more feet above ground line; it most frequently affected stem segments less than 3 years old. Butt sweep probably starts when the tree is less than 6 years old following one to several successive seasons of snow gliding. These three deformities involve stem bends, probably exceeding 45° from the vertical at maximum snow load and pressure. Stem sweep apparently is the result of snow creep at any level forcing the entire tree from the vertical; the root collar zone most often serves as the fulcrum. Stem sweep occurred after several snow seasons (possibly in succession); the tree never quite regains its upright stature during succeeding seasons. The most noticeable and damaging stem failures result from snow loads bending older, more rigid stem sections (fig. 6A). However, buckling of young stem segments (fig. 4A) was the most frequent failure within Class 6. Some of these failures, as well as some dog leg deformities, could have been the result of a vertical snow load pressing down on the crown of a tree that had a curved stem.

The obvious question arising from our assessment of this damage is "Will stem deformities acquired before age 15 years constitute permanent defects and, thereby, significantly reduce utilizable volume when affected trees are harvested 45 to 65 years later ?" Although wood utilization and marketing studies could provide factual data in 40 to 60 years, at least 2 to 8 feet of the butt log of most deformed trees now seems to be either wholly unusable for lumber or contains defects reducing product quality. Therefore, the resulting loss would be large in affected trees grown on a short rotation for lumber or poles.

As with many "point-in-time" studies, the end result (type, frequency, or severity of deformity) is a composite series of events, which we could not define in a cause-effect relation. However, it is apparent that the snowpack and its movement contribute significantly to stem deformities in stands regenerated on clearcuts in heavy snowpack zones. Thus, if snowpack damage is as serious as is indicated by our study, management practices to forestall such damage need to be considered. For example, if clearcutting is the appropriate choice for harvesting, barriers to snow movement might be necessary to reduce damage to the regeneration. The simplest barriers (though not the most desirable from either esthetic or management viewpoints) could be 4- to 6-foot stumps in view of the height where most deformities originate. Perhaps partial cuts, coupled with either natural or artificial regeneration, could resolve stand reestablishment problems on some sites as well as reduce the deformity losses.

Also, management has few guides for cultural practices in young stands in deep-snowpack zones. Our data suggest a high probability that this young stand will suffer continuing and severe deformities because (1) many small trees (currently, the least deformed) were left for crop trees and (2) thinning (to a density of 300-400 stems/acre as in our unit) eliminated much of the impeding influence that the excess stems might have provided against snow movement.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1972 - 780 - 954/136 REGION N

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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USDA Forest Service
Research Note INT-159

April 1972

RESPONSES IN A WESTERN WHITE PINE STAND TO COMMERCIAL THINNING METHODS

Marvin W. Foiles[1]

ABSTRACT

*Effects of crown and selection thinning at two levels (20 percent and 35 percent volume removed) and of no thinning were compared in an 87-year-old mixed conifer stand dominated by western white pine (*Pinus monticola *Dougl.) and grand fir [*Abies grandis *(Dougl.) Lindl.]. The 35-percent crown thinning produced the best diameter growth response and resulted in least mortality during the 10 years following treatment. Net annual volume growth per acre was highest on the control plots (837 board feet), but was nearly as high for light-crown thinning (776 board feet). Light selection thinning was almost as effective as the crown thinnings, but 35 percent selection thinning resulted in excessive mortality and reduced net volume growth.*

Stands of the western white pine (*Pinus monticola* Dougl.) type tend to be overstocked, and the effect of overstocking on timber yields has not been fully recognized until recent years. It has been estimated that natural, well-stocked western white pine stands at rotation age of 120 years have only 43 percent of the board-foot volume they could have if stocking were controlled through regular thinnings (Wikstrom and Wellner 1961).

Past experience has shown that small sawlog stands have suffered heavy mortality due to overstocking. Watt (1960) found that mortality nullified 10 to 44 percent of the gross board-foot volume growth in stands 70 to 100 years of age. The forest manager's problem, then, is to find a management system that will take advantage of the high productive capacity of western white pine sites without losing a large part of that production to mortality. The present study was begun in 1953 to explore the

[1]Silviculturist, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

possibility that a commercial thinning at about 80 years of age might keep these stands in a thrifty, vigorous condition less susceptible to mortality agents.[2] Such thinning might also increase growth on residual trees and utilize anticipated mortality.

Since this experiment began, administrators of the National Forests in the Northern Rocky Mountains reexamined their management programs after finding that control efforts against the blister rust fungus (*Cronartium ribicola* J. C. Fisch.) on western white pine had failed. In the realignment of priorities, administrators decided to favor other species in planting, weeding, and thinning programs until an effective and economical method of controlling blister rust was found (Ketcham, Wellner, and Evans 1968). Although management of western white pine is no longer emphasized, results of this experiment are worthwhile:

1. The region still contains considerable acreage of small saw timber stands that contain white pine;

2. Managers will not abandon white pine permanently. USDA Forest Service's Northern Region is beginning to plant western white pines that are genetically resistant to blister rust. These resistant trees are the result of vigorous USDA Forest Service research programs that also include efforts to develop biological or chemical rust control treatments. Continuing research should reestablish western white pine as an important component of managed stands in this region;

3. The stands on the study plots include other species that have benefited from the treatments.

STAND DESCRIPTION

The test was located on the Clearwater National Forest in northern Idaho in an even-aged stand dominated by western white pine. Study sites represented two habitat types described by Daubenmire and Daubenmire (1968): the *Thuja plicata/Pachistima myrsinites* habitat type, on north-facing slopes; and the *Abies grandis/Pachistima myrsinites* habitat type on all other sites. Grand fir [*Abies grandis* (Dougl.) Lindl.] was the chief associate of western white pine, but western larch (*Larix occidentalis* Nutt.), Douglas-fir [*Pseudotsuga menziesii* var. *glauca* Beissn.) Franco], western redcedar (*Thuja plicata* Donn), lodgepole pine (*Pinus contorta* Dougl.), Engelmann spruce (*Picea engelmannii* Parry), and subalpine fir [*Abies lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.] were also present.

The topography was gently rolling and plots were on all aspects, primarily on north- or east-facing slopes. Soils were deep, sandy loams underlain by basalt. Elevation was approximately 3,200 feet. In 1953 the stand age was 87 years. Based on the western white pine site index, site quality was excellent, varying between blocks from 77 to 86 (the average site was 79 feet at 50 years), according to Haig (1932). In comparison with normal yield-table values for stands of similar age and site quality, stocking in terms of basal area was down about 10 percent: in terms of cubic foot volume, it was almost the same; in terms of board-foot volume, it was about 6 percent higher (fig. 1).

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[2]This study was made in cooperation with the Clearwater National Forest personnel who administered the timber sale and protected the experimental area during the period of the study. C. A. Wellner assisted in designing and establishing the study; R. J. Boyd and G. H. Deitschman assisted in remeasurements of the plots and compilation of the data; all three are associated with the Intermountain Station.

Figure 1.--Before thinning, this 87-year-old stand was well-stocked, averaging about 230 square feet of basal area and 59,000 board feet per acre.

METHODS

The Clearwater National Forest sold timber from this experimental thinning according to regular commercial timber sale procedures. Logs were skidded by horse to minimize damage to residual trees. Logging slash was piled by hand and burned. The study was laid out in a randomized block design that called for five treatments and three blocks, or replications. Initially, each of the 15 plots was 1 acre in size, but one control plot was later reduced to 1/2 acre because of accidental logging disturbance. Treatments were randomly assigned to the plots in each block as follows:

1. *Light crown thinning.*--The main objective was to release the crowns of the best dominant and codominant trees by removing competing trees in the same crown classes. In addition, trees of poor vigor in all crown classes were cut (fig. 2). The intended cut was about 25 percent of the board-foot volume; the actual cut averaged 17 percent.

Figure 2.--Plot 508 as it appeared after light crown thinning in 1953. Crown thinnings gave increased growing space to the largest, most vigorous trees.

Figure 3.--Plot 506 after light selection thinning which harvested the largest stems and released well-formed codominant and intermediate trees. Compare with figure 2.

2. *Moderate crown thinning.*--This type of thinning is similar to light crown thinning only heavier. The intended cut was 40 percent of the board-foot volume; the actual cut averaged 35 percent.

3. *Light selection thinning.*--In contrast to the crown thinning treatments, the selection thinnings removed trees of largest diameters until the prescribed volume was cut (fig. 3). The intent was to release trees in the intermediate and codominant crown classes for future crop trees. A selected crop tree generally had a straight stem and few branches on the lower bole. It was hoped that release would promote rapid growth of quality timber. Light thinning was intended to remove about 25 percent of the board-foot volume; the actual cut averaged 21 percent.

4. *Moderate selection thinning.*--This type of thinning is similar to light-selection thinning only heavier. The intended cut was 40 percent of the board-foot volume; the actual cut averaged 34 percent.

5. *Unthinned control.*

All trees 5.6 inches d.b.h. and larger were included in the stand. Measurements of d.b.h., description of crown class, and crown condition were recorded for each tree. Sufficient heights were measured to construct a local volume table for each species. The effects of thinning treatments on stand parameters are shown in table 1. Trees were recorded according to cause of death when it could be determined. Net volume increments used were the differences between living tree volumes for the years of measurement. Gross increment was determined by adding periodic mortality to net increment. Diameter growth analyses by species and treatment were based on all residual trees in the stand. Analyses of variance and multiple-range tests were used to test treatment differences.

The plots were remeasured in 1958, 1963, and 1968. However, during the last 5 years, heavy mortality, mostly the result of western white pine blister rust and mountai[n] pine beetles (*Dendroctonus ponderosae* Hopkins), masked the effects of thinning treatments on stand growth. Therefore, growth was analyzed for only 10 years after thinning.

Table 1.--*Average stand conditions per acre before and after the 1953 thinning*

Thinning treatment	Trees[a]		Basal area		Cubic volume[b]		Sawlog volume[c]		Av. diameter	
	Before	After	Before	After	Before	After	Before	After	Before	After
	Number		*Square feet*		*M cu. ft.*		*M bd. ft.*		*Inches*	
Light crown	199	156	237	192	11.3	9.2	58.1	48.0	14.8	15.0
Moderate crown	183	106	214	135	10.2	6.5	52.4	33.9	14.7	15.3
Light selection	167	142	216	175	10.3	8.3	53.9	42.6	15.4	15.0
Moderate selection	204	160	226	158	10.7	7.3	54.2	35.7	14.3	13.4
Control	208	208	241	241	11.5	11.5	59.4	59.4	14.5	14.5

[a]Number of trees 5.6 inches d.b.h. and larger.

[b]Cubic feet of total stem, including top and stump, of trees 5.6 inches d.b.h. and larger.

[c]Board feet, Scribner rule, to a 6-inch top (d.i.b.), of trees 7.6 inches d.b.h. and larger.

RESULTS

Diameter Growth

The effect of thinning treatments on diameter growth of residual western white pine and grand fir trees was significant at the 5 percent level in an analysis of variance. Statistical differences between treatments as determined by multiple range tests are shown in figure 4. Grand fir responded better than western white pine to all four treatments. Grand fir growth improvement, over comparable control plots, ranged from 34 percent for light crown thinning to 63 percent for moderate crown thinning; however, western white pine in thinned plots grew only 11 to 35 percent faster than in the control plots.

Volume Growth and Mortality

Net annual gains in merchantable volume ranged from 492 board feet per acre on moderate selection plots to 837 board feet on control plots. The widest growth differences were statistically significant (fig. 5). Cubic volume increases ranged from 64 to 117 cubic feet per acre per year and treatments showed the same ranking as for board feet. In both cases, volume growth was more influenced by residual volume after thinning than by the thinning method.

However, volume losses due to mortality were related to the method of thinning (fig. 5). Over the 10-year period that followed crown thinning less mortality occurred among residual trees than among trees in the control plots. However, selectively-thinned plots actually showed an increased mortality rate. These results are logical when one considers the types of trees favored by the two thinning treatments. Crown thinnings released the strongest, most vigorous trees in the stand. Selection thinning, on the other hand, left the less vigorous codominants and intermediates in the residual stand. Such trees are smaller, less vigorous and more susceptible to mortality and to injury from wind, snow, and logging when the larger trees in stands are removed. Mortality was the major reason for the relatively poor net volume increment following selection thinning, particularly moderate selection thinning.

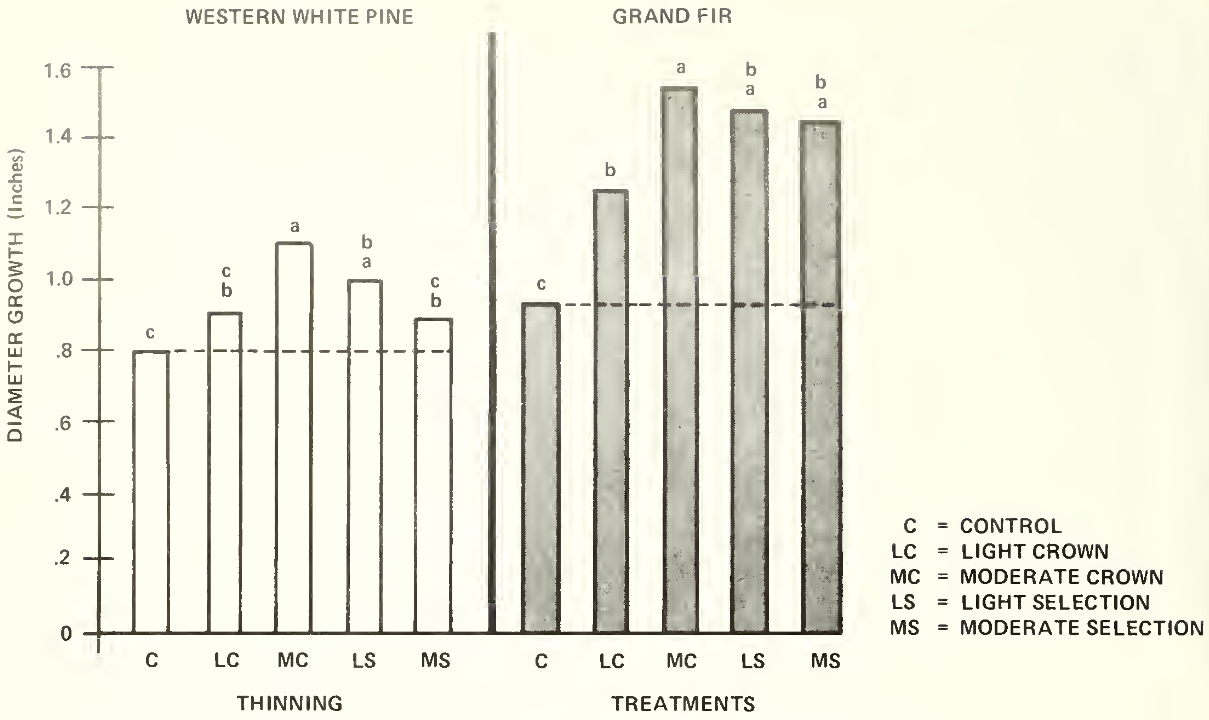

Figure 4.--Average 10-year-diameter growth per tree following thinning. (Growth means not indicated by the same letter are significantly different, P = 0.05.)

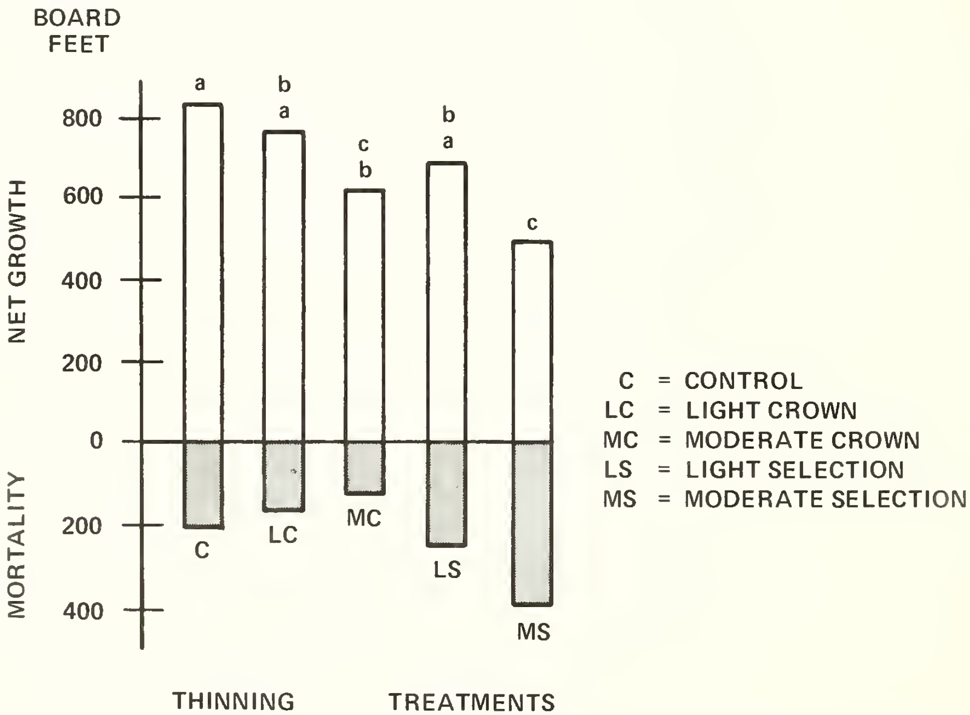

Figure 5.--Average annual board-foot growth and mortality per acre following thinning. (Increments not indicated by the same letter are significantly different, P = 0.05.)

DISCUSSION AND CONCLUSIONS

Commercial thinnings generally are intended to fulfill one or more of the following objectives: (1) to provide early monetary returns from the stand; (2) to reduce rotation length by improving the growth rate of residual trees; (3) to improve the quality of trees for the final harvest; (4) to utilize volume lost through mortality in unmanaged stands; and (5) to maintain near maximum volume growth per acre while fulfilling one or more of the other objectives.

How did the thinning treatments tested here compare in attaining the above objectives? No single treatment stands out as best for all purposes. However, moderate selection thinning was poorest for most purposes. Removal of so many large trees resulted in such heavy mortality and poor growth that this type of thinning is inadvisable under most circumstances.

Among the other three treatments, the choice should depend on the primary objective of thinning. If the main goal is to harvest anticipated mortality while maintaining near-maximum volume production, light crown thinning is the logical choice. If the primary objective is to increase diameter growth of residual trees, moderate crown thinning will give the best response. Light selection thinning permits harvesting the largest trees in a stand without significantly reducing the growth of residual trees. However, the trees left by selection thinning are smaller in average diameter; so they take longer to grow to a designated size.

Selection thinning might be appropriately applied to a mixed stand in which the dominant western white pines are infected with blister rust disease. Then, western white pines could be harvested while merchantable; this would release other species in the subdominant crown level for better growth.

Grand fir responded better than western white pine to all four treatments. However, the magnitude of the difference between species was greater for moderate selection thinning than for the other treatments. This difference reflects the response of trees in the lower crown classes to release by thinning. Grand fir is a more shade-tolerant species than western white pine. Tolerant trees in the lower crown classes retain relatively full crowns; therefore, they quickly utilize the increased growing space afforded them by thinning.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 - 781 - 055/150 REG

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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USDA Forest Service
Research Note INT-160

April 1972

UTILIZATION OF LODGEPOLE PINE LOGGING RESIDUES IN WYOMING INCREASES FIBER YIELD

R. B. Gardner and David W. Hann[1]

ABSTRACT

*Near complete harvesting in mature Wyoming lodgepole pine (*Pinus contorta *Dougl.) resulted in a 35-percent increase in weight of fiber removed compared to conventional harvesting.*

Because of the large volume of residues (tops, branches, dead and defective stems) that remain after most logging operations, land managers are forced to expend monies in many forest types for slash disposal to reduce fire hazards and for site preparation treatments to insure regeneration. Consequently, they have long sought alternative harvesting methods that would not only result in reducing the volume of residues remaining on the logged site but also increase the utilization of this material in the form of wood fiber yields.

Information regarding wood fiber yield is now available from the use of one such alternative harvesting method in a study currently being conducted by the Station in cooperation with U. S. Plywood-Champion Papers, Inc., and the USDA Forest Service, Intermountain Region. In this study, long-term effects of this method on ecological factors are being evaluated: namely, on regeneration, nutrient cycling, wildlife, esthetics, and hydrology. Hopefully, this pilot study also will provide cost-benefit information as well as some guidelines as to how similar studies should be conducted in the future.

Unlike what occurs in typical harvesting operations, the volume data presented in this report are based on measurements taken before and after harvesting in addition to the volume that was harvested. It should be borne in mind that this study involves only one species and one stand condition. Thus, these data are not necessarily applicable to other logging operations.

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[1]Respectively: Engineer in Charge, Forest Engineering Research, stationed in Bozeman, Montana, at Forestry Sciences Laboratory, maintained in cooperation with Montana State University; and Assistant Resource Analyst, Ogden, Utah.

STUDY PROCEDURE

Two lodgepole pine (*Pinus contorta* Dougl.) stands near Union Pass on the Teton National Forest in western Wyoming were selected for study. Each was relatively homogenous with respect to number, size, and spatial distribution of trees.

Within each of these stands, a study block was established, which was divided into two harvesting units. One harvesting unit was clearcut according to "conventional" standards, and the other unit was clearcut using new standards, which we chose to term "near complete" harvesting. Both the "conventional" and "near complete" standards called for the removal of all sound trees to a merchantable top diameter of 6 inches. In addition, the "near complete" standards required on-the-site conversion to chips of (1) tops of all merchantable trees; (2) all remaining standing trees with a d.b.h. of 3 inches or larger, including sound dead trees; and (3) all sound dead material remaining on the ground that was more than 6 inches in diameter at the larger end and that was more than 6 feet long.

How Measurements Were Taken

Measurements taken before the four units were harvested produced estimates of (1) stand volume, (2) number of trees, (3) site index, and (4) the volume of wood material lying on the ground (table 1 and fig. 1). A systematic sample grid served as the basis for selecting the locations that were measured, using a random start. The number of locations so selected in each unit follows:

Unit 1, "near complete" harvest	25
Unit 2, "conventional" harvest	31
Unit 3, "conventional" harvest	33
Unit 4, "near complete" harvest	39

Each location consisted of three plots superimposed on each other: (1) a variable plot, on which a 40-BAF angle prism was used to measure trees 5.0 inches d.b.h. and larger; (2) a 1/300-acre fixed plot on which all trees less than 5.0 inches d.b.h. were measured; and (3) a 50-foot transect[2] along which ground material 3 inches in diameter and greater was measured. One tree was measured on each location for determination of site index.

After harvesting, a systematic sample grid of twenty 50-foot transects was used in each unit to estimate the volume of material 3.0 inches in diameter and greater remaining on the ground (see table 1).

WEIGHT AND VOLUME OF MATERIAL HARVESTED

The weight of the logs harvested was obtained by weighing the loaded trucks; the weight of the chips harvested by measuring the volume of chip piles using aerial photogrammetric techniques and applying a conversion factor of 14.4 lb./cu.ft. (table 2). There was no significant difference between blocks or between treatments in total tons (unadjusted) per acre removed as the following analysis of variance (ANOVA) shows:

Source	*df.*	*SS*	*MS*	*F ratio*
Blocks	1	113.423	113.423	0.0850^{NS}
Treatment	1	1,159.403	1,159.403	$.8688^{NS}$
Error	1	1,334.448	1,334.448	

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[2]James K. Brown. A planar intersect method for sampling fuel volume and surface area. Forest Sci. 17(1): 96-102. 1971.

Table 1.--*Description of study stands before and after harvesting*

Item	Block 1: Unit 1 Treatment: near complete harvesting	Block 1: Unit 2 Treatment: conventional harvesting	Block 2: Unit 3 Treatment: conventional harvesting	Block 2: Unit 4 Treatment: near complete harvesting
Area of unit (acres)	16.8	21.7	22.5	17.2
Average stand age	168.7	166.0	185.4	178.0
Average site index (50-yr. base)	43.7	42.7	39.9	41.8
Volume/acre to 6-in. top of live standing trees (cu.ft.)	5,912	7,167	6,131	5,182
Volume/acre to 6-in. top of dead standing trees (cu.ft.)	1,014	1,016	1,120	1,064
Total volume/acre to 6-in. top (cu.ft.)	6,926(±621)[1]	8,183(±580)	7,251(±555)	6,246(±452)
Volume/acre of tree residuals[2] (cu.ft.)	1,124(±205)	1,460(±252)	797(±132)	752(±105)
Volume/acre of ground material ≤ 3 in. in size (cu.ft.)	1,820(±308)	1,182(±175)	1,478(±237)	2,482(±315)
Preharvest total volume/acre (cu.ft.)	9,870(±723)	10,825(±656)	9,526(±618)	9,480(±561)
Postharvest volume/acre of ground material ≤ 3 in. (cu.ft.)	564(±118)	3,589(±378)	3,545(±536)	894(±331)

[1]Figures in parentheses are 68-percent confidence intervals.
[2]Tree residuals is the difference between total volume for trees 3.0 in. d.b.h. and larger, and merchantable volume to a 6-in. top for trees 6.5 in. d.b.h. and larger.

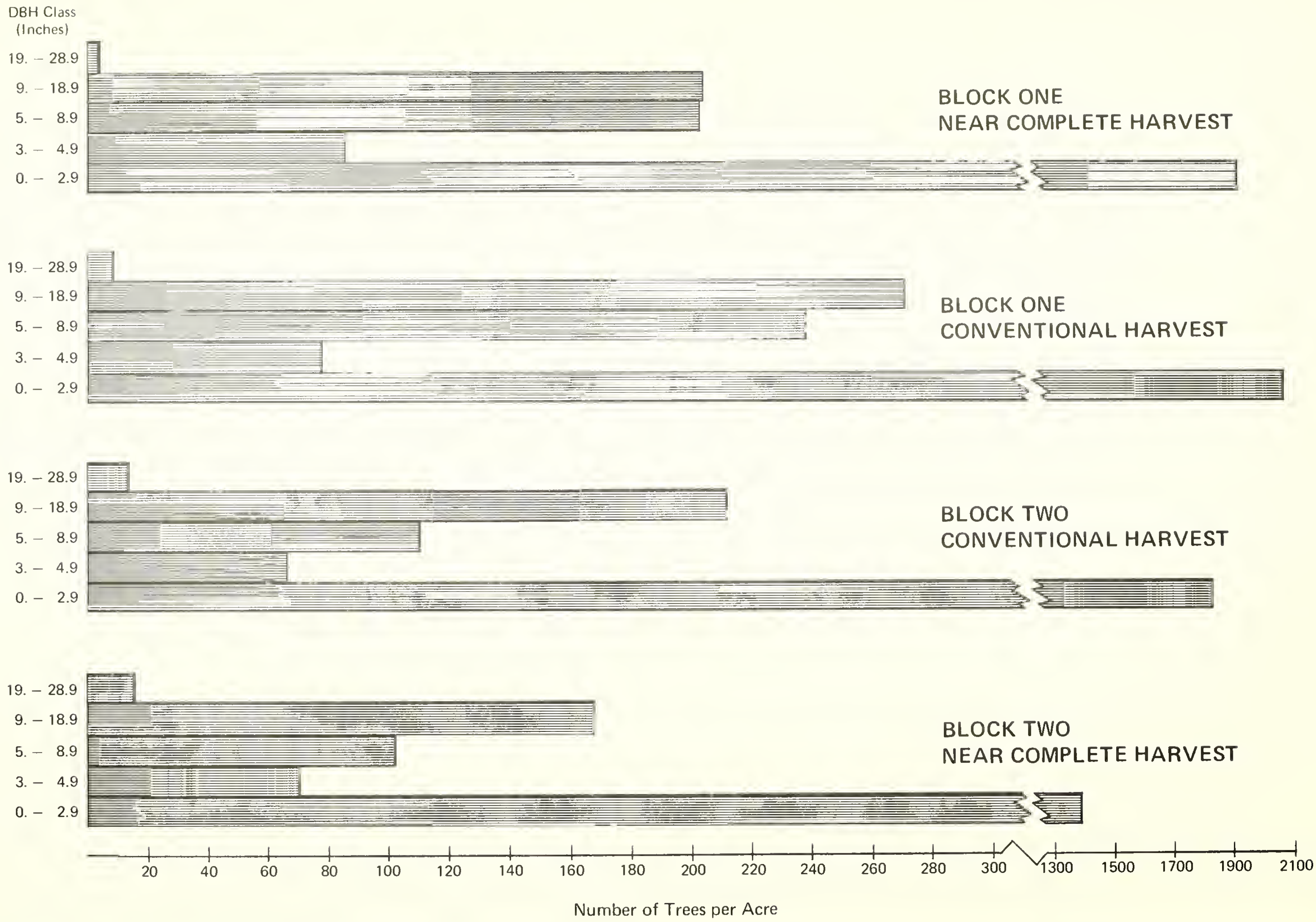

Figure 1.--Number of trees per acre by d.b.h. class.

Table 2.--*Volumes and weights (green) per acre of wood removed from study stands*

Harvest type	Unit No.	Merchantable logs		Chips		Unadjusted total weight	Adjusted total weight
		MBF	*Tons*	*Cu.ft.*	*Tons*	*Tons*	*Tons*
BLOCK 1							
Near complete	1	14.7	70.8	11,780	84.9	155.7	163.2
Conventional	2	25.1	129.5	0	0.0	129.5	123.8
BLOCK 2							
Conventional	3	21.4	111.0	0	0.0	111.0	110.7
Near complete	4	15.2	74.9	10,700	78.0	152.9	153.3

This result was not surprising; the experimental design necessitated an extremely large and consistent difference between treatments to be statistically significant. However, the difference could be of practical importance.

To permit reasonable comparison between treatments, differences in weight removed were adjusted for preharvest total volume differences on the four units. For each block, the difference between the preharvest total volume estimate on a treatment unit and the average preharvest total volume estimate was calculated and expressed as a proportion of the preharvest total volume on the treatment unit. This average was then applied as a correction factor to the original estimates of the weights of wood harvested from the units (table 2). These adjusted weights were then averaged as follows:

	Tons/acre
Average of adjusted weights of material removed from units 1 and 4	158
Average of adjusted weights of material removed from units 2 and 3	117
Difference	41
Percent difference	35

DISCUSSION AND CONCLUSIONS

Harvesting to the "near complete" removal standards resulted in retrieval of 35 percent more fibre than when conventional harvest standards were used.

The difference in merchantable weight of logs actually harvested (table 3) between the two treatments cannot be explained by differences in live merchantable volume that was measured before harvesting. We believe this difference might be largely attributable to our observation that some merchantable logs were chipped inadvertently. This occurred because the tree-length logging requirements imposed for the study made it impossible to cut merchantable sections out of green trees having rotten butts. Moreover, the more stringent standards posed problems for the crews. Future studies should be designed to have tighter controls over what material will be chipped and what will be removed as logs.

Table 3.--*Comparison of preharvest merchantable volume estimates of live standing trees with actual weight of merchantable logs removed from study blocks*

Harvest type	Unit No.	Inventoried volume (to 6-in. top)	Difference	Actual weight	Difference
		Cu.ft./acre	*Percent*[1]	*Tons/acre*	*Percent*[1]
BLOCK 1					
Near complete	1	5,912	17.5	70.8	45.3
Conventional	2	7,167		129.5	
BLOCK 2					
Conventional	3	6,131	15.5	111.0	32.5
Near complete	4	5,182		74.9	

[1] $\frac{\text{Conventional-Near complete}}{\text{Conventional}}$ X 100.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT- 161

May 1972

EFFECTS OF REMOVING POLE-BLIGHTED WESTERN WHITE PINE TREES ON GROWTH AND DEVELOPMENT OF A MIXED CONIFER STAND

Charles D. Leaphart and Marvin W. Foiles[1]

ABSTRACT

*A mixed conifer stand, in which western white pine (*Pinus monticola *Dougl.) was infected with the pole blight disease, was treated by removing either (a) all blighted trees, or (b) merchantable blighted trees. Neither treatment significantly altered the development of pole blight in the residual stand for 17 years following the cutting. The Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco) component suffered heavy mortality, caused mostly by* Poria weirii *root rot; therefore, it had negative net growth for the period. Western redcedar (*Thuja plicata *Donn.), the predominant understory conifer, responded well to release and accounted for much of the basal area and cubic volume increment.*

Pole blight is a disease of complex origin affecting primarily dominant and codominant western white pine trees (*Pinus monticola* Dougl.) between the ages, usually, of 40 and 100 years. Evidence to date (Leaphart 1958; Leaphart and Stage 1971) indicates that the disease is triggered by prolonged periods of climatic drought when such trees having these characteristics are grown on soils of low moisture storage capacity (less than 5.0 inches in the upper 3-foot mantle) and on sites with low moisture recharge potential (e.g., upper or midconvex slopes).

In 1952, an 85-acre experimental area was installed on the Kaniksu National Forest in northern Idaho to test the effects of two types of overstory removal on (a) development of the pole blight disease in western white pine and (b) growth of understory conifers, particularly western redcedar (*Thuja plicata* Donn). Graham (1958) had found that by 1957, there was no significant difference among treatments on pole blight development. Since then, however, the blister rust fungus (*Cronartium ribicola* J. C. Fisch. ex Rabenh.) has confounded the first objective by causing death of enough western

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white pines so that progress of pole blight in the treated areas has been masked. Therefore, in this report we are concerned with growth responses and mortality of other species as well as of western white pine through 1969 when final measurements were made.

EXPERIMENTAL AREA AND STAND DESCRIPTION

The experimental area was located in a mixed conifer stand covering several thousand acres. Most of the area represented an intermingling of two ecological habitat types: the *Tsuga heterophylla/Pachistima myrsinites* type and the *Thuja plicata/Pachistima* type. Western redcedar was the predominant species in the understory of both of these types. The *Abies grandis/Pachistima* and *Pseudotsuga menziesii/Physocarpus malvaceus* habitat types were represented on smaller acreages of the drier upper slopes (Daubenmire and Daubenmire 1968).

Species composition and site productivity varied, especially between the moist, protected lower slopes and the drier, exposed ridges. The stand was even-aged, about 74 years old in 1952. Until the appearance of pole blight some 10 years previously, vigor of the stand had been good. The average site index was 70, based on the height of western white pine at 50 years of age (Haig 1932).

Plot elevations ranged from 2,600 to 3,200 feet. The plots extended from the foot of a north slope to a main east-west ridge. Four main intermittent streams drained the area to the north. Slopes averaged 25 percent having steep pitches up to 40 percent.

The soil was a very fine sandy loam. On gentle slopes, the soil was deeper than on the steep slopes and on ridgetops. Also, there was less rock in the surface layers on the gentle slopes. The parent material was a shale. Occasional gravelly sands or fragipans inhibited root penetration at depths between 18 and 24 inches. Over most of the area, available moisture storage capacity ranged between 5 and 6 inches in the upper 3 feet of soil.

EXPERIMENTAL DESIGN

The experimental area was divided into nine subunits of about 9.5 acres each. The following treatments were randomly applied in a Latin-square design to the nine subunits:

1. Control--no cutting;

2. Cutting of merchantable pole-blighted western white pine trees; and

3. Cutting of merchantable pole-blighted western white pine trees as well as poisoning of nonmerchantable trees.

A sample plot, composed of five 1/5-acre subplots, was established within each subunit. Diameters of trees >3.5 in. d.b.h. on these forty-five 1/5-acre plots were measured in 1952 (after completion of cutting) and in 1969. Heights of a sufficient number of trees were obtained in 1952 on each subplot to construct height-diameter curves for volume determinations; these heights were adjusted for the 1969 volume determinations.

Trees were examined for pole blight symptoms in 1952, 1955, 1957, and 1959, but not subsequently because of blister rust. Death of any tree and its cause, when determinable, were recorded when diameters were measured.

RESULTS

Analyses of variance of net growth and of mortality between 1952 and 1969 revealed no significant differences among treatments within any species. Therefore, only the means of the treatments by species are shown in table 1.

The impact of diseases, whether from blister rust or pole blight, on growth of western white pine was not altered by treatment. For most western white pines, the cause of death was impossible to determine. However, inasmuch as blister rust was rather randomly distributed throughout the 85 acres, we assume that western white pines that died from it were also randomly distributed. Considering this assumption to be valid, we believe that the trend observed by Graham (1958)--treatments had no influence on pole blight development--held through 1969 because we also found no significant differences in either growth response or mortality in western white pines resulting from the treatments.

DISCUSSION

Despite lack of significant response among other species to treatment, two other notable events are illustrated by the data (table 1): (a) Compared to other species, Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) suffered a marked growth loss in many subplots; and (b) western redcedar accounted for much of the basal area and cubic foot volume increment for the test period.

When the plots were established in 1950, high mortality of Douglas-fir was noted in a few localized areas. In 1969, most of the subplots had many dead Douglas-fir trees in all size classes. This mortality was caused primarily by *Poria weirii* root rot, recognized in the early 1940's as a potentially serious management problem for many Douglas-fir stands on the West Coast (Bier and Buckland 1947) but not for this stand at the start of the study. For all plots combined, the significance of the impact of this disease is reflected in actual loss of Douglas-fir increment amounting to nearly 14 cu.ft./acre/year (table 1). This loss contrasts with a potential net increase of nearly 23 cu.ft./acre/year for a comparable Douglas-fir component of normal western white pine stands having similar site and age characteristics (Watt 1960). Because no feasible control is yet available for *Poria* root rot (Childs 1970), "what the experimental design should have been to reduce losses from it" is perhaps a moot question. Nevertheless, our current knowledge would have suggested salvage of unhealthy appearing trees as a minimum effort.

With the release from cutting, as well as from mortality, of overstory trees, diameter growth of western redcedar responded in all plots; but the response varied considerably according to the original diameter and degree of release given each tree; e.g., the largest trees and those with least overstory competition usually responded with greatest diameter increment. Diameter increment averaged 2.9 inches for all trees on our plots, and some individuals grew as much as 6 inches. The lack of significant difference in growth response as a result of treatment is attributed, at least in part, to relatively equal release; i.e., overstory removal plus mortality in treated plots approximated that from mortality alone in the check plots.

Table 1.--*Stand statistics per acre for 1952 and for the 17-year treatment period (1952-1969)*

Species and treatment No.[1]	Trees[2]		Basal area		Cubic volume		Sawlog volume		1952-69 mortality	
	1952	Net increment	1952	Net increment	1952	Net increment	1952	Net increment		
			Square feet		*Cu.ft.*		*Board feet*		*Cu.ft.*	*Bd.ft.*
WESTERN WHITE PINE										
1	83	-30	72	-4	3,123	-34	15,516	844	859	4,035
2	69	-18	59	7	2,656	463	13,025	3,514	404	1,744
3	63	-15	57	8	2,583	458	12,897	3,396	288	1,212
DOUGLAS-FIR										
1	46	-13	47	-2	1,603	0	7,218	586	347	1,458
2	58	-23	56	-8	1,952	-207	8,495	18	591	2,254
3	50	-25	47	-16	1,623	-504	6,896	-1,606	776	3,232
WESTERN REDCEDAR										
1	73	41	16	19	343	502	657	1,166	12	0
2	30	22	6	14	122	384	164	898	6	0
3	33	32	5	16	114	412	14	874	5	2
OTHER SPECIES										
1	55	-4	40	1	1,180	37	5,935	408	259	952
2	28	8	21	7	788	257	3,291	1,370	28	65
3	38	1	28	5	1,039	202	4,195	1,218	129	459
ALL SPECIES										
1	257	-6	175	14	6,249	505	29,326	3,004	1,447	6,445
2	185	-11	142	20	5,518	897	24,975	5,800	1,029	4,063
3	184	-7	137	13	5,369	568	24,002	3,882	1,198	4,905

[1]Treatments: 1. Control, no cutting; 2. merchantable pole-blighted western white pine trees harvested; 3. merchantable pole-blighted western white pine trees harvested and unmerchantable ones poisoned.

[2]Trees 3.6 inches d.b.h. and larger.

The released western redcedars appeared vigorous and healthy, in contrast to those reported by Koenigs (1969). In his study, all the overstory trees were removed in a single cutting and the redcedars responded with rapid diameter growth for about 5 years, after which growth drastically slowed down and the trees developed chlorosis and resinosis. However, through 1970 we have noted a gradual increase of vigor and growth rate in many trees in the area studied by Koenigs. In our study, the cutting and subsequent mortality completely released some trees, but this release was gradual throughout the 17-year period. The apparent difference in results indicates a need for study of the response of western redcedar to different rates and amounts of release on varying sites. Also, even though the present growth rate is maintained, many more years will be required to harvest a substantial crop of cedar products from the area, primarily because of small average diameters of the trees at the start of the study.

Similarly mixed stands of the western white pine type usually have considerable mortality from all causes, averaging 2,520 bd.ft./acre in a comparable 20-year age period (Watt 1960). In this stand, mortality in western white pine, Douglas-fir, and lodgepole pine (*Pinus contorta* Dougl.)[2] was the chief reason for the check plots not achieving their potential increment. Additionally, some of the western white pine and Douglas-fir trees alive in 1969 were not growing as rapidly as might be expected, primarily because of the debilitating effects of their respective diseases. Most mortality and growth losses resulted from the combined effects of three diseases rather than from the effect of only pole blight. Whether the total losses could have been reduced, or should have been salvaged, by clearcutting or some other treatment in 1952 is not defined by our study because only the western white pine component was treated. Although mortality was higher in the study area (table 1) than reported by Watt, it was still lower than that occurring now in many other western white pine pole stands having similar disease problems. Thus, our study suggests that managers can greatly benefit from knowledge of the total disease complex prior to scheduling cultural operations, even if these operations can do little more than salvage impending mortality.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of R. F. Watt, who installed the study and who, with D. P. Graham, made many of the early periodic measurements; and of the many others in the Intermountain Station and the Kaniksu National Forest who assisted in plot installation, periodic measurements, and study termination.

[2]Lodgepole pine is a short-lived species in habitats represented in the study unit; it accounted for most of the loss noted for the "other species" category in table 1.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1972 - 781 - 118/154 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-162

June 1972

ABUNDANCE OF ARTHROPODS INHABITING DUFF AND SOIL AFTER PRESCRIBED BURNING ON FOREST CLEARCUTS IN NORTHERN IDAHO[1]

David G. Fellin and Patrick C. Kennedy[2]

ABSTRACT

Abundance of some arthropods inhabiting the duff and soil on three clearcut areas that were prescribed burned was investigated in northcentral Idaho. Generally more arthropods were present and more taxa were represented on older burns. In duff samples, the Acarina, Chilopoda, Thysanoptera, Protura, and Thysanura were most numerous in more recent burns. Acarina comprised 77 percent of the fauna in the duff samples. Soil samples collected before mid-July contained about 90 percent of the total number of individuals--mostly immatures--especially on the oldest burn. The most abundant arthropod in the soil samples on the oldest burn was the carabid Amara erratica *(Sturm). Because of the abundance of this carabid and its seed-eating behavior, it is recommended that direct seeding of western white pine (*Pinus monticola *Dougl.), and perhaps of other conifers, be done the first or second season after prescribed burning.*

Wildfires are known to reduce the abundance of soil animals--at least temporarily. In a longleaf pine (*Pinus palustris* Mill.) forest in the Southeast, Heyward and Tissot (1936) found soil microfauna (mostly arthropods) to be 11 times more abundant in both the A_0 horizon and the upper 2 inches (5.08 cm.) of mineral soil on unburned areas than in respective soil depths on burned areas. A study of soil arthropod populations in the Pine Barrens of New Jersey (Buffington 1967) showed significantly higher populations of arthropods on unburned as compared to burned areas. Buffington's samples from the unburned areas were usually richer in both numbers of taxa and of individuals. In

[1]Based on part of a thesis entitled "Biotic factors influencing direct seeding of western white pine *(Pinus monticola)*" prepared by the junior author in partial fulfillment of the requirements for a master's degree in forestry at the University of Michigan.

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Finland, Huhta and others (1967) demonstrated that burning-over of residues (slash) following tree harvesting was very destructive to all groups of soil animals. They noted that many groups were permanently affected, but that other animal groups might find conditions more favorable later and experience a more or less temporary population resurgence if the organic layer was deep enough to remain at least partly unaffected by the fire.

It is common practice in the forests of the northern Rocky Mountains to broadcast burn slash and unmerchantable trees following logging. These fires consume varying levels of duff[3] exposing proportionate amounts of mineral soil. Partial or complete exposition of mineral soil is desirable as a seedbed for germination of many species of forest tree seed and as a site for planting coniferous seedlings. Burning also removes vegetation that competes with developing young trees. Logging followed by prescribed burning usually also provides a desirable habitat for many vertebrates, particularly ungulates--a habitat that often is more favorable than that provided by dense forest cover. At the same time, fires influence the habitat of invertebrates living in the duff and upper layers of mineral soil.

In this study, our objectives were to (a) determine the relative abundance of arthropods inhabiting the duff and upper mineral soil 1, 2, and 3 years after clearcut areas were prescribed broadcast burned, and (b) identify those arthropods that might be a threat to successful coniferous regeneration by direct seeding.

STUDY AREA AND PROCEDURE

We conducted our study[4] during 1963 in the Musselshell area of the Clearwater National Forest in northern Idaho. Ecologically, most of the area is in the *Thuja plicata-Pachistima myrsinites* habitat type; a smaller portion on the more severe southerly and southwesterly exposures is in the *Abies grandis-Pachistima myrsinites* habitat type.[5] The topography of this area is characterized by rolling low hills having a maximum relief of about 200 feet (60 m.); slopes vary from near zero to about 30 percent.

Three areas, which range in size from 50 to 1,900 acres (20 to 769 ha.) were selected for study. Each had been clearcut, and then prescribed burned in the late summer or early fall of 1960, 1961, and 1962, respectively. The intensity and depth of burning varied somewhat both within and between the three areas.

By 1963, the vegetation on the three burns was quite variable. On the 1960 burn, the most abundant types of vegetation found were grasses, sedges, and mosses; occasionally, some thistles (*Cirsium* spp.) and fireweeds (*Epilobium* spp.) were found (fig. 1). On the 1961 burn, thistles and fireweeds were predominant, interspersed with other herbaceous plants. On both the 1960 and 1961 burns, shrubs were abundant but they were small and inconspicuous. On the 1962 burn, there was virtually no living vegetation during the early spring of 1963 (fig. 2), but some thistles invaded the area during the late spring and early summer.

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[3]Forest litter and other organic debris in various stages of decomposition, on top of the mineral soil, typical of coniferous forests in cool climates where rate of decomposition is slow, and where litter accumulation exceeds decay.

[4]This study is only a portion of a more comprehensive study concerning the biotic factors that influence the direct seeding of western white pine (*Pinus monticola* Dougl.). The overall study was established by and is under the supervision of Raymond J. Boyd, Associate Silviculturist, stationed in Moscow at the Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

[5]Daubenmires' classification (1968).

Figure 1.--Portion of clearcut burned in 1960 as seen in early spring of 1963. Grasses, sedges, and mosses are the predominant vegetation; thistles and fireweed were less abundant. There are also quite a lot of small and inconspicuous shrubs hidden from view by the other vegetation. Stakes and exclosure seen in photo were used for another study.

Figure 2.--Portion of clearcut burned in late fall of 1962 as seen in early spring of 1963. There is virtually no living vegetation, though charred stumps and partially burned logs are abundant. Rodent exclosure in background was used for another study.

Eight transects, two on each of four major aspects, were randomly selected in a 10-acre (4 ha.) plot on each of the three burns in early May of 1963. One sample was collected along each transect in each burned area every 2 weeks between May 10 and August 1; thereafter, on August 29 and September 26. Samples consisted of a vertical core of duff and soil 5 inches (12.75 cm.) in diameter and 8-1/2 inches (21.5 cm.) deep. Though the volume of each sample was the same, the proportion of duff and mineral soil often differed because of varying depths of the duff layer. All sampling was done during daylight hours between 8:00 a.m. and 5:00 p.m.[6]

Duff and mineral soil portions of each sample were treated differently. During each collection, the duff was removed from the surface of each core sample and the eight samples from each burn combined and transferred to one of three Berlese-type funnels where they were left for 2 weeks. The mineral soil in each core sample, kept separate by transect and date of collection, was spread out on a piece of heavy canvas where it was carefully sifted for insects and other arthropods.

ARTHROPOD ABUNDANCE IN MINERAL SOIL

The older the burn, the more individuals were found; one notable exception was the chilopods (table 1). There were about twice as many taxa represented in the 1960 and 1961 burns as in the 1962 burn.

Carabids, principally *Amara erratica* (Sturm), comprised about 66 percent of the total number of individuals collected on the 1960 burn; they were present in 35 of 72 samples. They were also found during eight of the nine sampling periods.

We found very little difference in the proportion of individuals on each of the four aspects in samples from the 1960 burn as shown in the following tabulation:

Aspect	*Percent of individuals found*
North	31
South	24
East	22
West	23

We were unable to make such a comparison with the data on the 1961 and 1962 burns because so few individuals were collected.

Arthropods were most abundant in soil samples taken during late spring and early summer (table 2). Considering all three burns, about 90 percent of the material was taken in samples collected through July 19. Ninety-six percent of the 118 carabids from the 1960 burn were found in samples collected on or before July 19.

Regardless of the year of burn or sampling date, immature specimens in the samples nearly always outnumbered the adults (table 2). In the 1960 burn, 68 percent of the total number of individuals were immatures; in the 1961 burn, 94 percent were immatures. There were no adults in the samples from the 1962 burn. Interestingly, 71 percent of the 118 carabids in the 1960 burn were immatures, both larvae and pupae.

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[6]Recently, Drake and others (1971) reported that pre-dawn appears to be the best time for sampling soil arthropods.

Table 1.--*Relative abundance of insects and other arthropods collected from samples of mineral soil on 1-, 2-, and 3-year-old burns*

Taxa	1960 burn		1961 burn		1962 burn	
	N*	T**	N	T	N	T
Coleoptera						
Carabidae						
(Principally *Amara erratica* (Sturm))	118	35	5	5	0	0
Chrysomelidae	9	4	15	3	0	0
Elateridae	1	1	4	4	2	2
Staphylinidae	2	2	0	0	0	0
Scarabaeidae	1	1	0	0	0	0
Curculionidae	10	1	2	2		
Cicindellidae	0	0	2	2		
Other	9	10	8	7	1	1
Hymenoptera	0	0	4	2	0	
Diptera	8	7	2	2	3	2
Lepidoptera	3	3	1	1	0	
Hemiptera	2	2	1	1	0	
Homoptera	6	2				
Collembola	0	0	0		2	1
Chilopoda	3	3	5	3	10	6
Diplopoda	0	0	3	2	1	1
Nematoda	5	2	1	1	4	2
Symphyla	1	1				
Total individuals	178		53		23	
Total taxa	14		13		7	

*N = the total number of individuals found in all transects at all sampling periods.
**T = the number of times, out of 72, a taxon was represented.

Table 2.--*The relative number of immature and adult arthropods collected from samples of mineral soil on 1-, 2-, and 3-year-old burns*

Date sample collected	1960 burn		1961 burn		1962 burn	
	Immature	Adult	Immature	Adult	Immature	Adult
May 10	35	1	8	0	0	0
May 23	19	3	2	0	3	0
June 6	31	15	1	1	17	0
June 20	33	10	6	2	1	0
July 5	4	5	12	0	1	0
July 19	5	7	11	0	0	0
Aug. 1	2	2	3	0	1	0
Aug. 29	1	0	4	0	0	0
Sept. 26	5	0	3	0	0	0
Total individuals	135	43	50	3	23	0

ARTHROPOD ABUNDANCE IN DUFF

Considering all taxa, the total number of individuals collected in samples from the 1962 burn was nearly half again as great as the number in samples from either the 1960 or 1961 burns (table 3). Excluding the Acarina, arthropods in samples from the 1960 burn outnumbered those from the 1961 burn by more than five times and were nearly four times more abundant than those from the 1962 burn. The number of taxa represented in duff samples from each burn was about the same.

Acarina accounted for a large percentage of the total number of individuals, regardless of the year of burn. On the 1962 burn, the mites comprised 46 percent of the total fauna; on both the 1961 and 1962 burns, about 90 percent of the organisms collected were mites. Besides the mites, the chilopods and three insect orders--Thysanoptera, Protura, and Thysanura--were most abundant on the 1962 burn.

In material collected in the duff samples, we found no consistent decreasing trend in the total number of individuals collected during late summer or early fall, as we did with the soil samples.

DISCUSSION

We suspect that the greater relative abundance of individuals on the 1960 and 1961 burns can be attributed to movement from adjacent unburned forests as well as to repopulation from survivors within the burned areas. In their work in the Southeast, Heyward and Tissot (1936) indicate that even very hot surface fires rarely heat the underlying soil to more than 176° to 194° F. (80° or 90° C.) at a depth greater than 1/4 inch (0.62 cm.) below the surface. They said: ". . .if either the animals themselves or their eggs were only 1/4 to 1/2 inch beneath the soil surface, they would stand an excellent chance of escaping harm during the fire."

However, a recent study[7] on an experimental area prescribed burned in late July during hot and dry weather in the northern Rocky Mountains showed that an extremely hot surface fire generated temperatures as high as 300° F. (149° C.) at a depth of 5/8 inch (16 mm.) on portions of the burn. No doubt most insects would have had to be deeper than 5/8 inch into the soil to survive such temperatures. However, because intensity of heat varied, average and maximum temperatures at a depth of 5/8 inch in other parts of the burn were considerably lower. Soil insects at this depth in these portions of the burn could have survived.

We did not find any ants (Hymenoptera: Formicidae) in our samples from any of the burns. Neither did we observe any ants on the burned areas. Interestingly, Heyward and Tissot (1936) found Formicidae to be the third most representative taxon (following Acarina and Collembola) in soils of a longleaf pine forest in the Southeast. In a study in New Jersey, several species of Formicidae comprised 93 percent of the total number of individuals on a burned area and 96 percent of the individuals on an unburned area (Buffington 1967).

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[7]R. C. Shearer. Soil moisture, soil temperature, and root mortality associated with prescribed burning in western larch forests. Intermountain Forest and Range Exp. Sta., Ogden, Utah 84401. (In preparation).

Table 3.--*Relative abundance of insects and other arthropods collected from samples of duff on 1-, 2-, and 3-year-old burns*

Taxa	1960 burn		1961 burn		1962 burn	
	N*	T**	N	T	N	T
Coleoptera						
Carabidae						
(Principally *Amara erratica* (Sturm))	26	7	2	2	1	1
Curculionidae	1	1	2	1	0	0
Staphylinidae	6	4	2	2	1	1
Other	35	8	26	7	27	7
Collembola						
Sminthuridae	7	4	1	1	0	0
Entomobryidae	88	7	13	4	5	4
Poduridae	246	8	10	4	5	4
Diptera	13	5	8	4	4	3
Lepidoptera	5	4	1	1	0	0
Hymenoptera	32	5	1	1	2	2
Hemiptera	26	5	0	0	3	1
Homoptera	26	9	2	1	6	1
Thysanura	7	3	5	3	18	5
Protura	3	2	0	0	19	2
Thysanoptera	14	6	20	5	29	2
Acarina	475	9	929	8	1,260	9
Araneae	9	4	3	2	8	2
Chilopoda	7	4	5	3	22	4
Nematoda	1	1	0	0	0	0
Symphyla	0	0	0	0	1	1
Pseudoscorpionida	0	0	0	0	4	1
Total	1,027		1,030		1,414	
Total (without Acarina)	552		101		154	
Total taxa	19		16		17	

*N = the total number of individuals found in all transects at all sampling periods.

**T = the number of sampling periods, out of 9, when a taxon was represented.

Of particular interest to us was the abundance of carabids, principally *Amara erratica*, in both the mineral soil and duff samples from the 1960 burn when compared to the scarcity of these beetles in samples from the 1961 and 1962 burns (tables 1 and 3). Such relative population differences could indicate decimation of *A. erratica* populations by the prescribed burning and a resurgence of the species 3 years later.

In another phase of our studies that concerned insects affecting western white pine following direct seeding on these same prescribed burns, we found *A. erratica* to be the principal seed destroying insect (Kennedy and Fellin 1969). In this study, we often observed and collected it on our study plots on the 1960 burn. A projection based on sample data from the 1960 burn indicates that there could have been up to 100 carabids per square yard (91.5 $cm.^2$) of soil surface.

Since our study was completed in 1963, direct seeding of western white pine has been discontinued (Ketcham, Wellner, and Evans 1968). If it's resumed, however, we feel that seeding should be done the first or second year following burning. After that, increasing carabid populations could substantially reduce the probability of successful regeneration. Our data indicates that carabids not only increase in number by the third year following burning, but that they are most abundant early in the season when seeds are lying in the duff or on the soil surface before germination. We speculate that these carabids will also eat seeds of other coniferous species, such as grand fir (*Abies grandis* (Dougl.) Lindl.), and western redcedar (*Thuja plicata* Donn), growing in association with western white pine as well as seeds of conifers not associated with western white pine. If so, any direct seeding programs for these species should also be planned for the first year or two following prescribed burning.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-163

August 1972

SOIL WATER DISTRIBUTION ON A CONTOUR-TRENCHED AREA

Robert D. Doty[1]

ABSTRACT

Six years of soil water measurements on and adjacent to a contour-trenched area revealed that some redistribution of soil water occurred following trenching. However, trenching did not alter the soil water conditions sufficiently to significantly change water yields from the catchment. A reduction in water use from trench bottoms was offset by an increased loss from the cut-bank and trench fills. No change in soil water was apparent between trenches.

Watersheds along the crest of the Wasatch Mountain Range in Utah were so severely overgrazed, burned, and deforested around the turn of the century that accelerated erosion resulted in frequent mud-rock floods during high-intensity summer rainstorms. Rehabilitation practices, initiated in the early 1930's, included contour trenching (Bailey 1947). Trenching is still used where watershed conditions dictate that trenching is necessary to stabilize the soil until vegetation can be reestablished. During the past 10 years the practice has been questioned by water users who fear that it could eventually reduce water yields. In 1964, studies were started to determine what effects trenching might have on the timing and the volume of water yields other than the recognized reduction of peak flows from summer storms. Associated with this work were soil water measurements which are reported here.

In this paper, the term "soil water" is used in place of the more familiar term "soil moisture" to stress the fact that the neutron probe used to measure water in the soil makes no distinction as to the water's state or type of bonding (retention or detention) that may be related to its presence.

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[1]Associate Research Forester, stationed in Logan, Utah, at Forestry Sciences Laboratory, maintained in cooperation with Utah State University.

The Halfway Creek drainage, Davis County Experimental Watershed, Farmington, Utah, was contour trenched during the summer of 1964. A year later, access tubes to facilitate soil water measurements were installed on seven plots (fig. 1). Four tubes were placed in each plot. Four plots were on the trenched area and three were on an adjacent untrenched area, making a total of 28 sample points. Tubes on each of the trenched area plots were located so that one tube was midway between trenches, one was 2 feet above the trench cut bank, one was in the bottom of the trench, and a fourth was on top of the trench fill (fig. 2).

Soil water measurements were made in the spring and mid-September of each year from 1966 through 1971. Using the neutron probe technique, measurements were made to a depth of 6 feet at 1-foot intervals. Spring readings were made as soon as possible after snowmelt, which varied from early May to mid-June. Precipitation, snow distribution, vegetation, and streamflow measurements were also taken during this study.

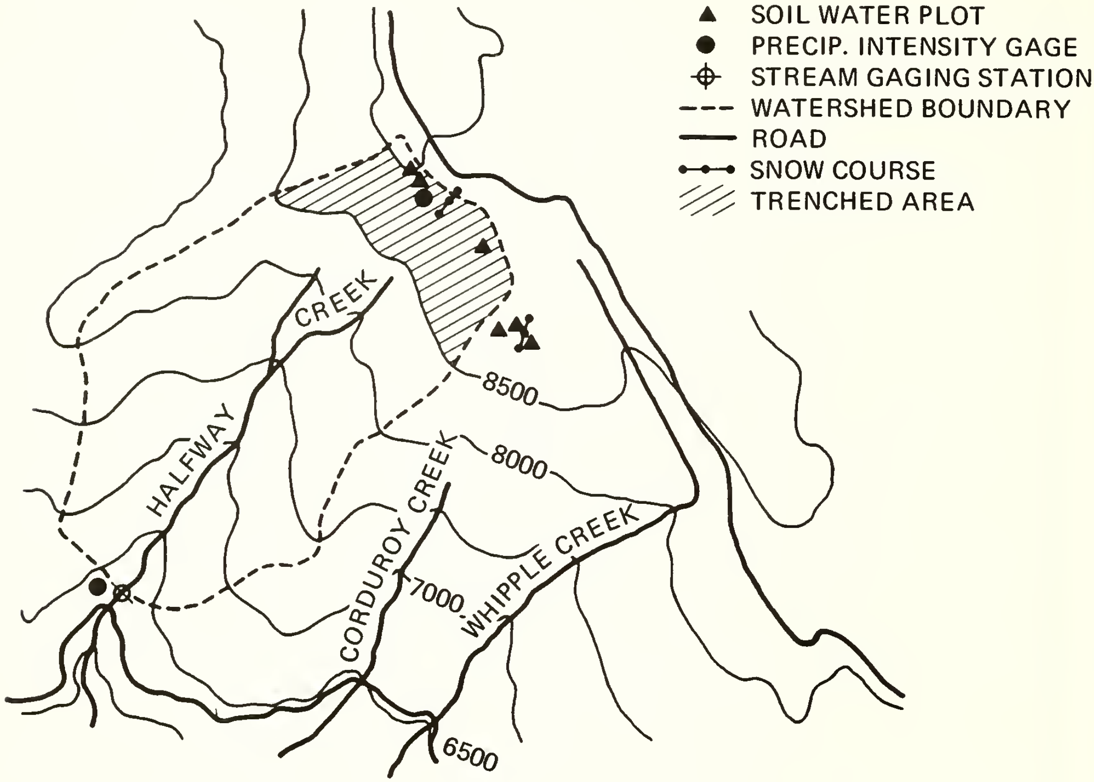


Figure 1.--Topographic map of Halfway Creek and adjacent drainages showing the location of contour trenches, soil water-access tubing plots and other instrumentation.

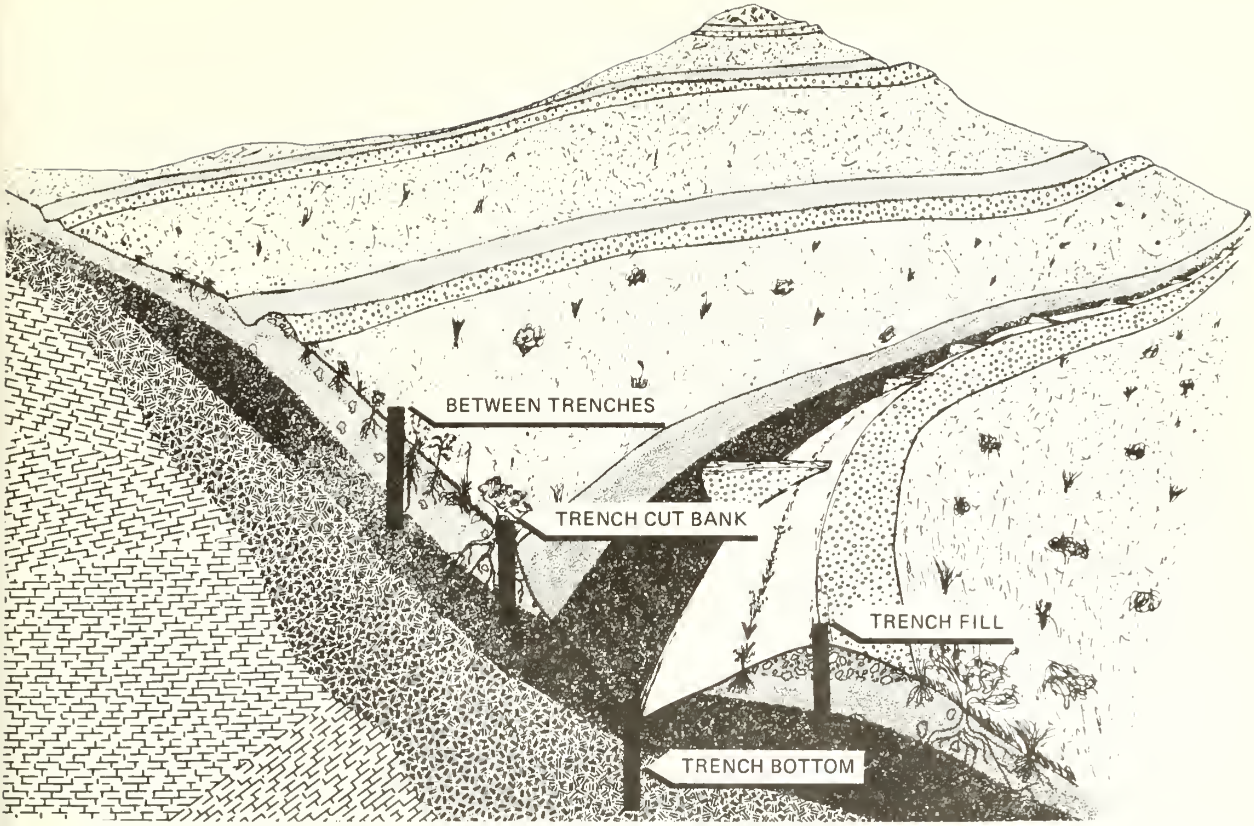


Figure 2.--Arrangement of soil water-access tubing on one of four plots in the trenched area of the Halfway Creek drainage.

RESULTS

Contour trenching disturbs the immediate trenched area but, in this study, caused no perceptible changes in the area between trenches. Vegetation that existed prior to trenching remained unchanged outside the disturbed area. Vegetation densities between trenches consist of 28 percent shrubs, 27 percent grass, and 4 percent forbs, a total of 59 percent live ground cover. The dominant cover is sagebrush *(Artemisia tridentata* and *A. scopulorum)*. Snow distribution was altered somewhat in the trenches themselves, but the average water content of the snow over the whole trenched area was similar to that on an undisturbed control area (Doty 1969). Also, a comparison of streamflow measurements before and after trenching shows little if any change in water yields attributable to trenching (Doty 1971). These factors indicate that trenching has not had a major effect on the soil water regime of the watershed.

Onsite redistribution of soil water was studied by comparing the measurements from each of the four access tubes with each other and measurements from control plots on the adjacent untrenched area (table 1). Only about 10 inches of water is held in the 6-foot soil profile in the spring prior to any appreciable loss through evapotranspiration. These are rocky, coarse-textured, immature soils of limited water-holding capacity. The high infiltration rates and pervious nature of these soils allow considerable water to move through the soil profile before the growing season begins.

Construction of the trenches apparently altered soil water conditions in trench bottoms. Trench construction displaced 3 to 4 feet of surface soil material. Consequently, soil water-access tubes in trench bottoms were in material at the 4- to 10-foot depths compared to the 0- to 6-foot depths of the intertrench tubes. Material at

Table 1.--*Average quantity of soil water by location in a 6-foot profile*

	Between trenches	Trench cut bank	Trench bottom	Trench fill	Untrenched control
	Inches				
Initial soil water	8.98	9.66	9.57	10.64	9.64
Growing season withdrawal	2.56	3.13	.95	2.66	2.98
Growing season precipitation	4.48	4.48	4.48	4.48	4.48
Total water loss	7.04	7.61	5.43	7.14	7.46

the 4- to 10-foot depths has a lower water-holding capacity. This was offset by gravitational water which was present at the time of spring readings due to shading, less wind, more snow, and later snowmelt. The delayed loss of this gravitational water elevated spring soil water readings to a level similar to most other locations. Further, during the growing season, shading and reduced wind in trench bottoms reduces evaporation losses and the lack of vegetation almost eliminates transpiration losses. These conditions, along with some lateral flow of water into this area, result in less net water loss from a trench bottom than from any other location during the growing season (fig. 3).

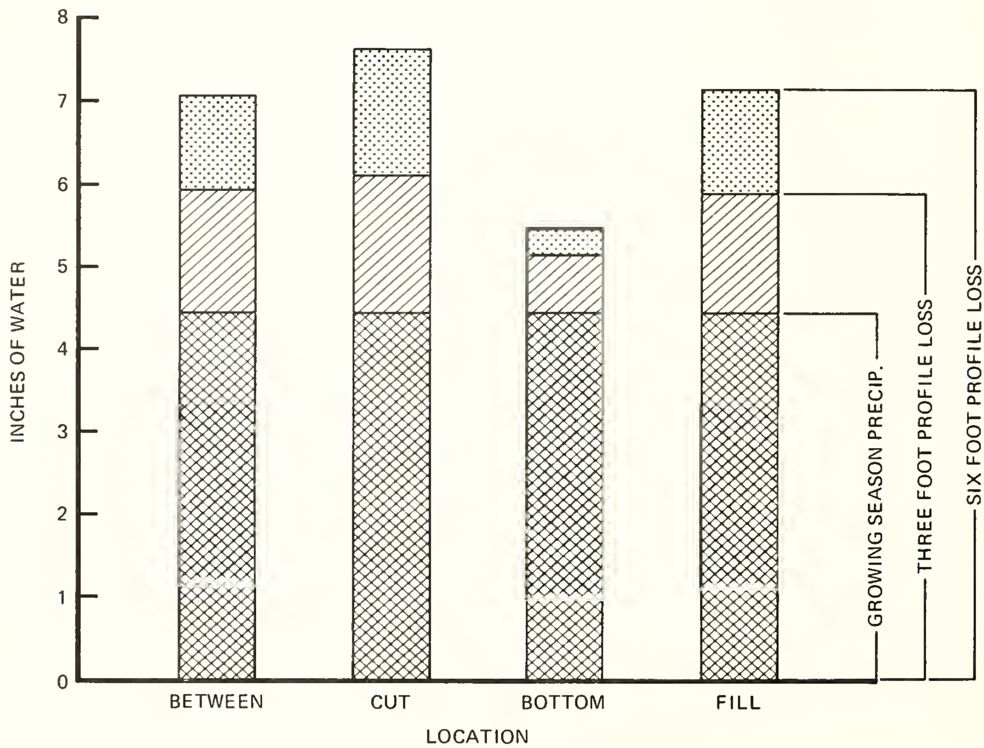
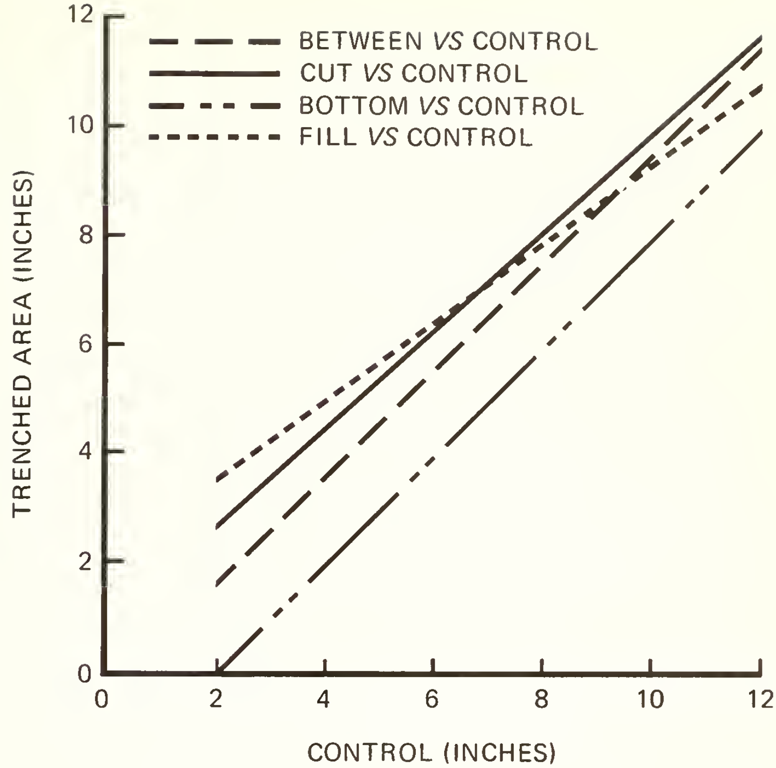


Figure 3.--Average soil water depletion during the growing season under four treatment conditions.

Figure 4.--Correlation of soil water depletion between individual locations and the control.



Trench fills are comprised of soil material from the trenches. This area, greatly disturbed by trench construction, changed each year as the material settled and vegetation became reestablished. More water is present in the trench fills in the spring; however, withdrawal from this material is similar to withdrawal elsewhere. Actually, the trench cut bank shows greater loss than the fills. Evaporation from the exposed cut bank could account for the measured increase. Development of vegetation on the trench fill during the 6 years of measurements has resulted in a trend toward increasing water loss with time, causing the relationship between the fill and the control to deviate from the one-to-one relationship evident on the other three locations (fig. 4). The other three locations measured show no discernible trend over time.

Most of the water withdrawn comes from the upper 3 feet of the soil mantle (fig. 3), as would be expected since most of the vegetation in the area is shallow-rooted. In comparing measurements to 3 and to 6 feet, it was assumed that precipitation during the growing season primarily affected only the upper 3 feet.

During the 6 years of measurement, only one or two storms each year produced a measurable amount of overland flow. Ponding of water in the trenches was not observed except during snowmelt. Soil water measurements made immediately before and after a heavy summer rainstorm showed that the soil had been wetted only to a 1- or 2-foot depth. Consequently, if one assumes that summer precipitation interacts with only the upper 3 feet of soil, then 80 percent of the evapotranspiration loss can be assigned to that layer. In the trench bottoms, nearly 90 percent of all water loss occurred from the upper 3 feet.

CONCLUSIONS

An area of immature and pervious soils, such as that trenched in Halfway Creek, retains relatively small amounts of soil water and readily gives up this water to shallow-rooted vegetation. Trenching results in some redistribution of the soil water, but does not significantly change water loss or resulting streamflow. The cut bank shows some increase in evaporation, whereas trench bottoms, due to a lack of soil and vegetation, show a reduction in loss. Seasonal water loss from the fill increased with time as vegetation occupied the site more completely. Most of the area (that between trenches) changed little if at all in respect to soil water retention or transmission.

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1972-781-636/4

Research Note
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-164

September 1972

ESTABLISHMENT OF *AGATHIS PUMILA* (RATZ.)[1] FOR CONTROL OF LARCH CASEBEARER,[2] AND NOTES ON NATIVE PARASITISM AND PREDATION IN IDAHO

Robert E. Denton[3]

ABSTRACT

Describes results achieved 10 years after the release of 2,360 Agathis pumila *in 1960 at five locations near St. Maries, Idaho, to establish biological control of larch casebearer. Information is provided on the potential role of native parasites and predators as biocontrol agents.*

Before 1957, defoliating insects had not posed a serious threat to western larch (*Larix occidentalis* Nutt.) stands, compared with most of the other coniferous stands in the northern Rocky Mountains. When infestations did occur, they were generally short-lived and didn't kill any trees.

In 1957, an infestation of larch casebearer, *Coleophora laricella* (Hbn.), was discovered near St. Maries, Idaho (Denton 1958). Since then, this infestation has spread unchecked: by 1958, it had spread over 15,000 acres in the Idaho panhandle and eastern Washington; by 1972, larch casebearer could be found over one-half of the western larch within its botanical range (fig. 1), and serious deterioration and mortality of trees were evident in many stands in northern Idaho (Tunnock and others 1969).

Chemical control of the casebearer in this large outbreak has not been attempted. However, if emergency control measures are necessary to protect valuable western larch resources, ultra low-volume application of technical grade malathion has effectively controlled larch casebearer in aerial spray tests (Denton and Tunnock 1968).

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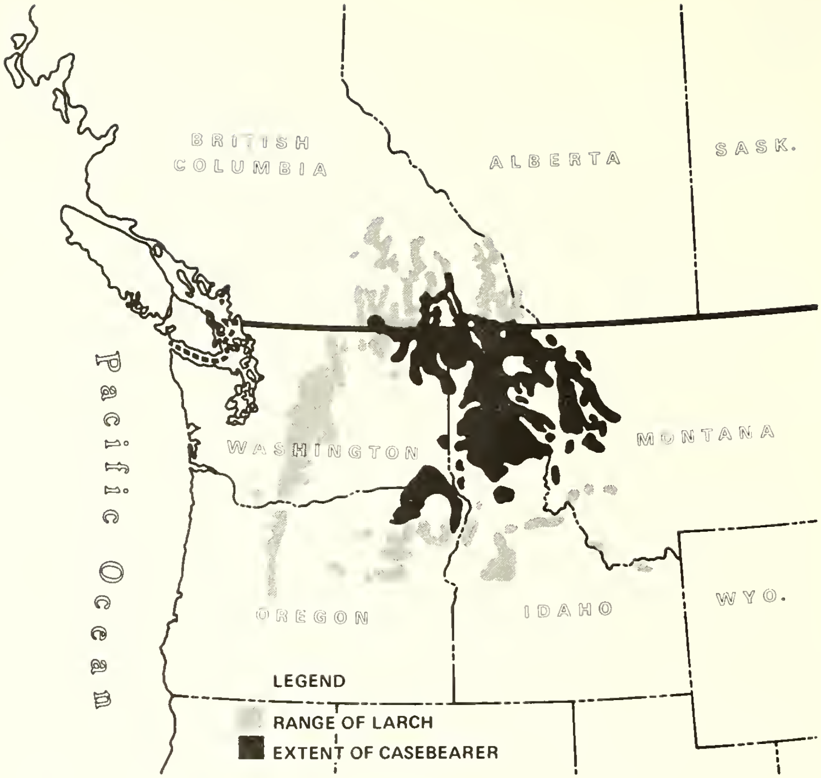
[1]Hymenoptera: Braconidae

[2]*Coleophora laricella* (Hbn.) (Lepidoptera: Coleophoridae)

[3]Research Entomologist, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, which is maintained in cooperation with the University of Idaho.

Figure 1.--Botanical range of western larch and extent of larch casebearer infestation within that range.



Furthermore, chemical control can only be expected to provide temporary population reductions. Thus, we are placing major emphasis on biological control through the introduction of proven insect parasites into infested western larch forests. To date, this program has been directed toward introduction and propagation of the primary parasite, *Agathis pumila* (Ratz.). This European braconid was introduced during the 1930's into Eastern United States and Canada and is credited with materially helping to check and control larch casebearer infestations there (Turnbull and Chant 1961).

PARASITE INTRODUCTION

In 1960, entomologists at the Northeastern Forest Experiment Station's former Forest Insect Laboratory at New Haven, Connecticut, reared several thousand *A. pumila* adults from larch casebearer collected in Rhode Island. These were then sexed to ensure a 1:1 ratio of males to females. The parasites were then placed in pint ice cream cartons (about 100 per carton) that were filled with loosely packed excelsior to serve as a perching site for shipping by air from New York City to Spokane, Washington. A piece of sponge soaked with watered honey provided moisture and food.

Five shipments were made on successive days beginning on June 23 (table 1) and released at five locations within a 30-mile radius of St. Maries, Idaho. The first shipment, which left New York City at 2:00 a.m. and was scheduled to arrive in Spokane at 2:00 p.m. on the same day, inadvertently went to Seattle, Washington, and was not received until the second day. Factors that probably contributed to the large amount of mortality in this shipment were: (1) The parasites had to be held in the New Haven Laboratory for more than a week to obtain the 1:1 ratio because the males began to emerge several days before the females; (2) the high altitudes and low temperatures

Table 1.--*Numbers of* A. pumila *released in the vicinity of St. Maries, Idaho, during June 1960*

Shipment No.	Number shipped	Percent mortality in transit	Number released	Location
1	1,025	70	305	Thorn Creek
2	500	7	464	Thorn Creek
3	500	19	404	Rocky Point
4	500	16	419	St. Joe City
5	1,000	23	372	Indian Canyon
			396	Calder

in the airliner baggage compartment; and (3) the delay in reaching Spokane. Consequently, the four subsequent shipments were put in the heated, pressurized forward compartment. Furthermore, we decided to release the *A. pumila* in the second shipment at Thorn Creek because the survivors of the first shipment did not appear vigorous.

No parasites from the five shipments were retained for local propagation because we had planned to rely on additional shipments from the New Haven Laboratory for several more years. However, in 1961, larch casebearer declined to such low levels in the East that it was not economically feasible to collect *A. pumila* there. Therefore, we could not undertake a large-scale *A. pumila* rearing and propagation program in Idaho until 1964 when sufficient numbers of parasites again became available from the East.

ESTABLISHMENT OF *AGATHIS*

In 1962, several specimens of *A. pumila* were recovered from mass rearings of larch casebearer collected at Thorn Creek, Rocky Point, and Indian Canyon. These recoveries showed that the parasite had gone through two generations and apparently was becoming established in Idaho. Since then the rate of parasitism has been determined every 2 years by rearing parasites from larch casebearer pupae in vials using Webb's technique,[4] or by dissecting overwintering larch casebearer larvae.

Although the parasite has been recovered in all five release locations, significant buildup has occurred after 10 years in only three of the areas (table 2). As of now, we can't explain why *A. pumila* populations have not increased at Thorn Creek or Calder. Furthermore, the overall effectiveness of the parasite has been limited by its failure to spread throughout the range of larch casebearer. The most distant recovery of *A. pumila* from an original release point has been only 6 miles. In sharp contrast, Cody and others (1967) reported that *A. pumila* spread nearly 30 miles per year for 12 years in Michigan. Following release of *A. pumila* adults reared in Idaho in 1965, parasitism increased to a maximum of 70 percent of the larch casebearer population within a quarter-mile radius of the release location, after which it began to decrease; this decrease became abrupt beyond a half-mile radius. We speculate that the lack of dispersal we experienced could be attributed to the excessively large numbers of larch casebearers that were immediately available. If this is true, then the rate of spread we experience in the future in these stands should increase when the numbers of casebearer are sufficiently reduced.

[4]F. E. Webb. An ecological study of the larch casebearer *Coleophora laricella* Hübner (Lepidoptera: Coleophoridae). Ph.D. Thesis, Univ. Mich., Ann Arbor. 1953.

Table 2.--*Parasitism of larch casebearer by* A. pumila *released in the vicinity of St. Maries, Idaho, during June 1960*[1]

Location	Year			
	1964	1966	1968	1970
	Percent			
Thorn Creek	0	1	0	2
Rocky Point	12	15	46	48
St. Joe City	14	46	48	42
Indian Canyon	10	16	68	66
Calder	--	2	0	1

[1]Some specimens were reared in 1962 from Thorn Creek, Rocky Point, and Indian Canyon.

The potential effectiveness of *A. pumila* in suppressing larch casebearer was shown in the Indian Canyon area where 372 parasites were released in a relatively isolated stand of western larch in 1960. In that year, the overwintering larch casebearer population averaged 278 larvae per 100 fascicles. In the following 8 years, parasitism increased to 68 percent (table 2) and the overwintering larch casebearer larvae averaged less than 20 per 100 fascicles. In the absence of appreciable spread, considerable mortality of *A. pumila* probably has occurred as the larch casebearer population was reduced. Yet in 1970, the percent parasitism remained almost constant at 66 percent. This shows that *A. pumila* is not only effective in reducing larch casebearer populations, but also can maintain a high level of parasitism even at low host densities.

NATIVE PARASITISM

Increasing numbers of native species of parasites are parasitizing the larch casebearer. In the area originally infested in 1957, three species (*Bracon pygmaeus* Provancher, *Pristomerus* sp., and *Spilochalcis albifrons* (Walsh)) were recovered in 1958. By 1968, aggregate native parasitism had increased to 17 percent and the number of species recovered had increased to 16, of which *S. albifrons* predominated. These included:

Braconidae	*Bracon pygmaeus* Provancher
	Bracon sp.
Ichneumonidae	*Bathythrix* sp.
	Campoplex sp.
	Gelis tenellus (Say)
	Gelis sp.
	Pristomerus sp.
	Scambus transgressus (Holmgren)
	Scambus sp.
Eulophidae	*Dicladocerus* sp.
	Tetrastichus coerulescens Ashmead
	Tetrastichus dolosus Gahan
Pteromalidae	*Amblymerus* sp.
	Habrocytus phycidis Ashmead
	Pteromalini (genus? species?)
Chalcididae	*Spilochalcis albifrons* (Walsh)

Undoubtedly, the number of species of native parasites attacking larch casebearer in the West will continue to increase--additional species are being recovered periodically. However, the ultimate role of native parasites as a controlling factor is questionable. In the East, Webb[5] reports more than 50 species of native parasites reared from larch casebearer. However, Webb did note "The native parasites...are chiefly notable for the large number of species represented rather than for achieving effective control."

NATIVE PREDATION

Thus far, information on predation of larch casebearer has been gained largely by direct observations. The major arthropod predators are mites and hemipterous bugs; to a far lesser degree, spiders capture larch casebearer larvae and ants have been observed dragging larvae to their mounds when the larvae have been forced to migrate in search of food.

Egg predation is an important factor in natural control. We found in this study that 42 percent of the eggs failed to hatch; 38 percent of this mortality was attributed to predation, mainly by a species of voracious large red mite, *Bdella muscorum* Ewing. This predator, along with hemipterons, also attacks larch casebearer larvae, especially when circumstances cause the larvae to wander without the protection of a case.

The most important arthropods observed preying on various stages of larch casebearer were:

Hemiptera
- Miridae
  - *Deraecoris* sp.
  - *Phytocoris* sp.
- Anthocoridae
  - *Anthocoris* sp.

Arachnida
- Bdellidae
  - *Bdella muscorum* Ewing
- Erythraeidae
  - *Balaustium* sp.

Birds are probably the most important vertebrate predators of larch casebearer; however, their importance as a regulatory factor has not been studied in the West. In Wisconsin, Sloan and Coppel (1968) reported that birds feeding on overwintering larvae were probably responsible for a 23.5 percent mortality of larch casebearer. Of 32 species of birds that they tested, 13 fed on larch casebearers.

The most common yearlong resident bird noted in western larch stands is the black-capped chickadee, *Parus atricapillus* L. Flocks of these birds have been observed searching larch trees and consuming considerable numbers of larch casebearer larvae, especially the overwintering stage. No observations have been made of birds feeding on moths. The U.S. Fish and Wildlife Service is currently engaged in a study to determine the species of birds that prey upon larch casebearer and their role as a natural control factor in the West.

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[5] *Ibid.*

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☆ U. S. GOVERNMENT PRINTING OFFICE: 1972-782 073/46

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-165

November 1972

ESTIMATION OF SURVIVAL AND GROWTH POTENTIALS OF NURSERY STOCK BY USING A "VARIABLE-MOISTURE-STRESS-PLOT" TECHNIQUE

Raymond J. Boyd, Steven McDonald, and Lee L. Mason[1]

ABSTRACT

A semicontrolled technique for testing the survival and growth potentials of conifer nursery stock under several soil-moisture-stress levels is described. The technique permits relatively efficient mass testing under conditions that virtually eliminate many of the extraneous variables associated with field testing. Some examples of test results are presented.

One of the prime functions of nurserymen and scientists engaged in nursery work is to improve the field performance of nursery-grown stock. Any change in nursery culture or stock handling practice must, regardless of early indications based upon general stock appearances or cost, face the ultimate test of what this change does to the ability of the stock to *survive* and *grow* under the rigors of field planting. Consequently, accurate and efficient evaluation of stock survival and growth potentials is an important function for those engaged in the production of forest planting stock.

This evaluation of stock capabilities takes on many different forms ranging from direct observations of performance in the field to indirect evaluation based upon real or imagined correlations, and from crude ocular estimates to scientifically sophisticated determinations. One of the most perplexing problems is choosing a technique that gives an accurate estimate of performance quickly and inexpensively. The ultimate means for accomplishing this is probably a well-designed field test, adequately replicated, repeated over a period of from 3 to 5 years to sample varying weather effects, and carefully controlled to minimize the confounding effects of extraneous variables, such as differences in planting skill, competing vegetation, diseases, insects, and animal damage. If all of these criteria are satisfied, excellent information should be obtained; however, the cost is high and results are slow to achieve.

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[1]Respectively, Silviculturist, USDA Forest Service, Intermountain Forest and Range Experiment Station, stationed at Moscow, Idaho, Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho; and Supervisory Foresters, USDA Forest Service, Northern Region, Coeur d'Alene Nursery, Coeur d'Alene, Idaho.

The authors gratefully acknowledge the assistance of the following personnel at Coeur d'Alene Nursery: Assistant Nurseryman David H. Gibney; Nursery Technicians Mrs. Bea Fischer and John Thompson; and Nursery Worker Clair Simmons.

Several years ago it became obvious to those of us associated with the planting program in the Northern Region of the USDA Forest Service that a good substitute for or supplement to field testing was needed. Previously, at least one major study effort was largely invalidated by a year during which the weather was extremely favorable for survival. Results of other studies were inconclusive owing to our inability to devote the time and money required for good long-term field testing. We therefore also concluded that expensive field testing of stock performance would have to be limited only to studies involving especially important questions and decisions.

We decided that an improved testing technique should allow us to determine the relative ability of different types of stock to survive under uniformly applied levels of moisture stress, because moisture stress has been proven to be the greatest single cause of field mortality, and is the climatic variable that most often confounds a single year's field testing. We also sought to insure that our technique would (a) minimize extraneous variables, such as animal damage, stock handling variables, and planting differences; (b) permit a large number of treatments to be replicated without the expense of individual tree marking; and (c) require a minimum of travel expense.

METHODS

The "Variable-Moisture-Stress-Plots" have been used to test the survival potential of various types of nursery stock on the Coeur d'Alene nursery for 3 years (1965-67). In our initial trial we used four stress levels (designated as low, moderate, high, and severe) in which stress was controlled by combinations of irrigation, weeding, no care, and shielding from natural precipitation. The extra precaution of a shielded plot (severe stress) was subsequently abandoned in favor of a three-stress-level approach. The given stress levels are maintained on adjacent "plots" in which seedlings from the nursery treatments being tested are planted approximately 1 foot apart in rows 18 inches apart (fig. 1). Rows of trees extend through the range of moisture stress being used; 24 trees are planted in each stress plot. Test trees are planted in April, May, or June and their survival and growth are examined throughout the first growing season and, depending on the circumstances, into the second or third season.. In order to standardize planting and reduce planting variability, seedlings are threaded into an eight-tree Yale Board under shelter and positioned in a plowed trench that has one vertical side. The trench is promptly backfilled and the soil packed into place (figs. 1 and 2). The soil is brought to field capacity when the seedlings are planted; after a day's planting, it is sprinkled to facilitate settling.

Figure 1.--Plowing the trench for planting a row of trees in the "Variable-Moisture-Stress-Plots."

Figure 2.--After trees are threaded into "Yale board" accurately positioned, the trench is backfilled and uniformly packed around seedling roots.

After planting, all plots are kept moist until late June or early July, when the "stressing" is started. At the start of the stressing period, special irrigation equipment[2] is installed on the low-stress plot (fig. 3). (Other less elaborate systems could be used. Overhead oscillating sprinklers have given good results if the low stress plot is placed to prevent inadvertent irrigation of the adjacent higher stress plots.) Low-stress plots are maintained weed-free to reduce the need for irrigation as much as possible. Soil-moisture-metering devices, either electrical resistance units or tensiometers, have been used to indicate soil moisture content and to provide information for irrigation control. The soils on the low-stress plots are kept roughly above 50 percent of available moisture at the 8-inch level. Stress levels on the other plots are controlled by the degree to which weed competition is removed, and they are varied according to the species planted. For ponderosa pine (*Pinus ponderosa* Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), we aim for a wide range of soil moisture--from the irrigated weed-free plots to a nonirrigated plot having a full component of weeds. With species that demand more moisture, such as western white pine

[2]LeRoy Schultz and Roland Stoleson. A precision sprinkler for soil moisture studies. Tree Planters' Notes 18(1): 15-17, illus. 1967.

Figure 3.--Overview of "Variable-Moisture-Stress-Plots" with automatic irrigator operating on the low-stress plot area.

(*Pinus monticola* Dougl.), Engelmann spruce (*Picea engelmannii* Parry), and grand fir (*Abies grandis* (Dougl.) Lindl.), we aim for a narrower range of soil moisture by partial weeding of the severe-stress plots and complete weeding of the moderate-stress plots.

The end result for which we aim is a range of survival from near 100 percent in the low-stress plot to 40 percent or less in the severe-stress regime. Theoretically, if we were to use enough stress levels, we should be able to find the level at which differences in survival and growth among the groups of stock being tested are the greatest. In actual practice we have found that three stress levels, judiciously controlled and varied according to the species being studied, are adequate for our purposes.

RESULTS

The moisture-stress-plot technique has been used to test the effects on survival of (a) seedbed density (fig. 4), (b) antitranspirant treatment of stock (fig. 5), (c) age classes (fig. 6), and (d) soil fumigation (fig. 7). It is currently being used in a test of stock storage methods on survival. Although the details of these tests are not included in this report, certain highlights are discussed to illustrate the effectiveness of the method and how to evaluate the results.

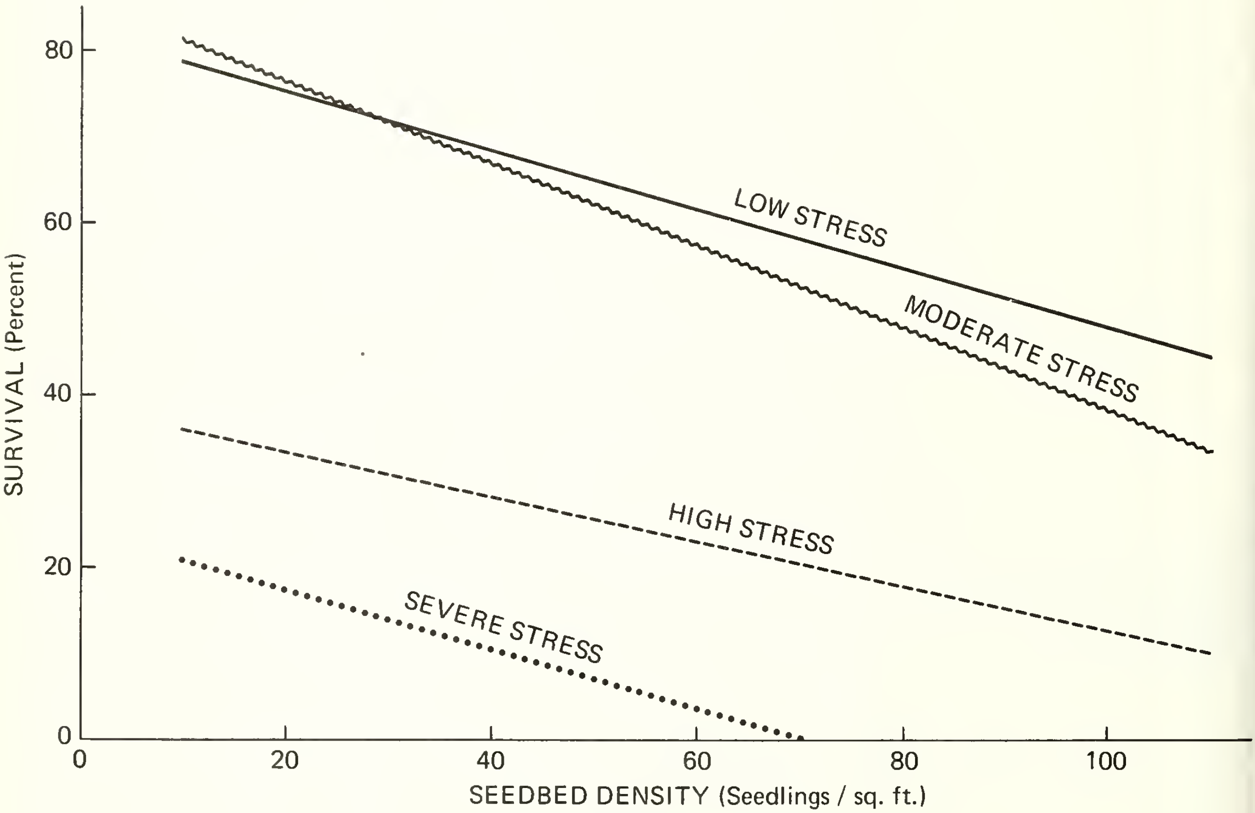

Figure 4.--The effect of seedbed density on survival of 2-0 ponderosa pine at various soil-moisture-stress levels (as of August 20).

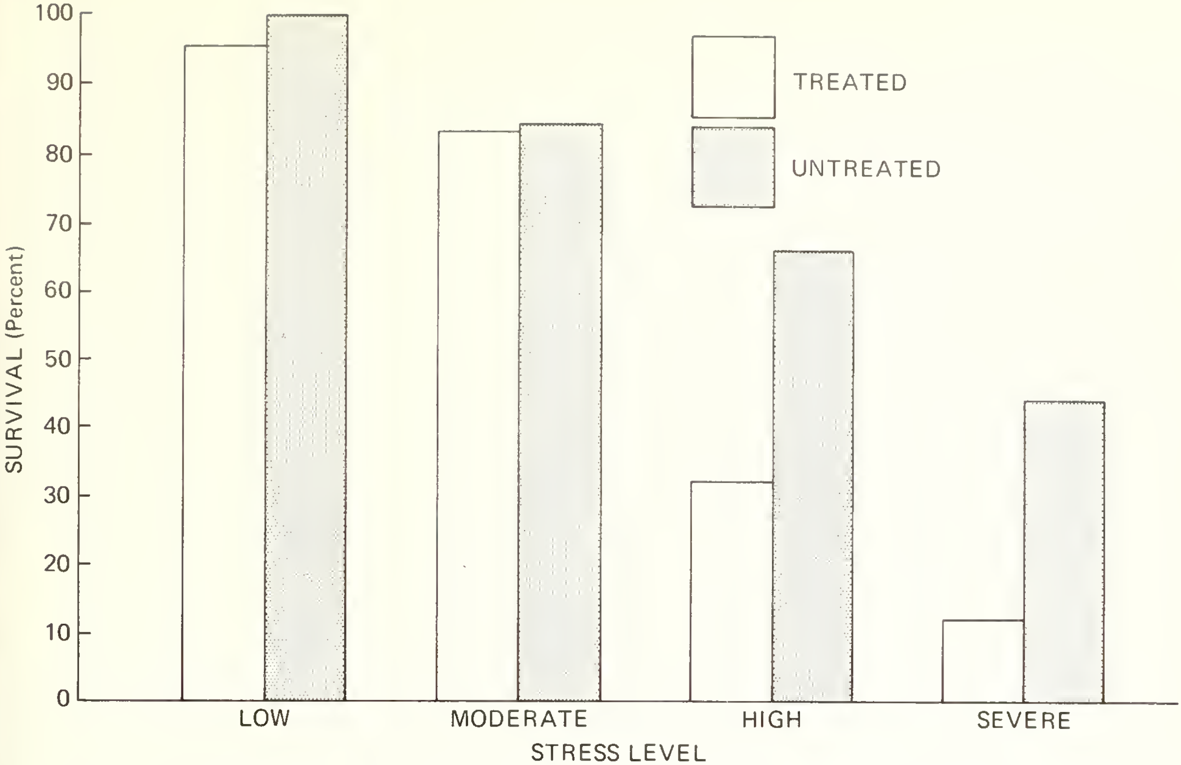

Figure 5.--The effect of antitranspirant treatment on the August 20 survival of 2-1 Douglas-fir growing at various moisture-stress levels.

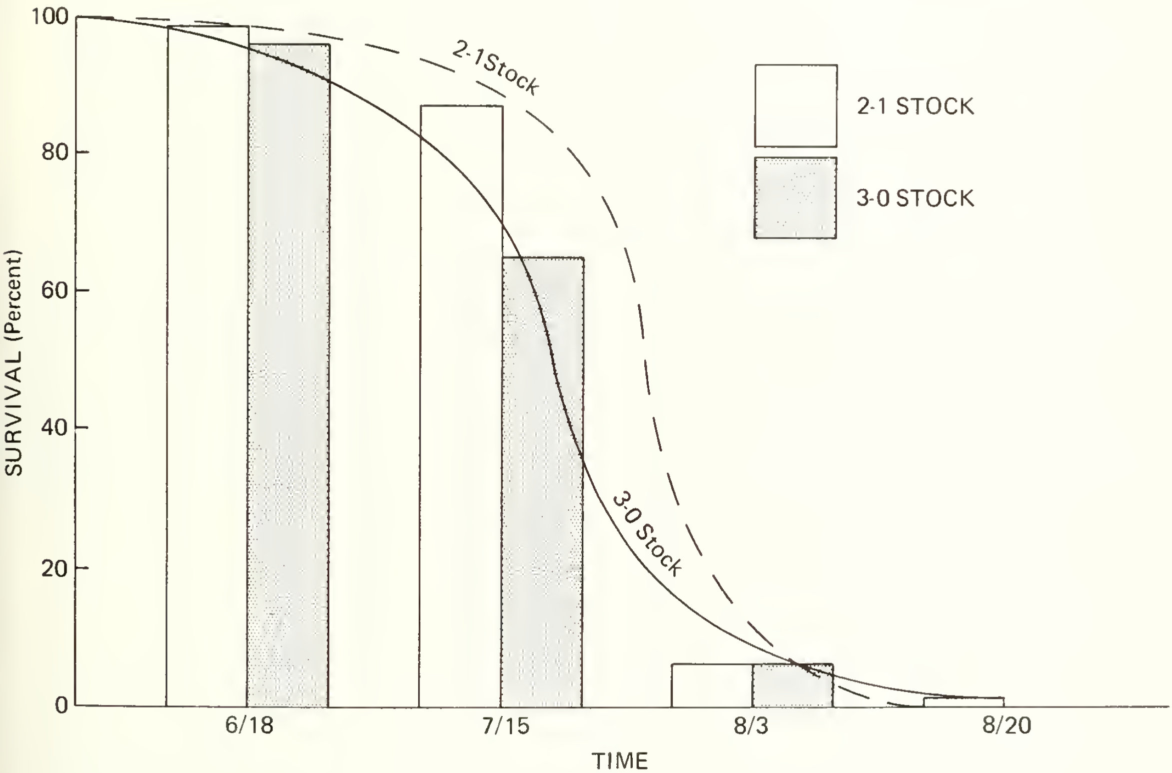

Figure 6.--First-year survival trends of 2-1 and 3-0 Engelmann spruce under severe soil-moisture stress.

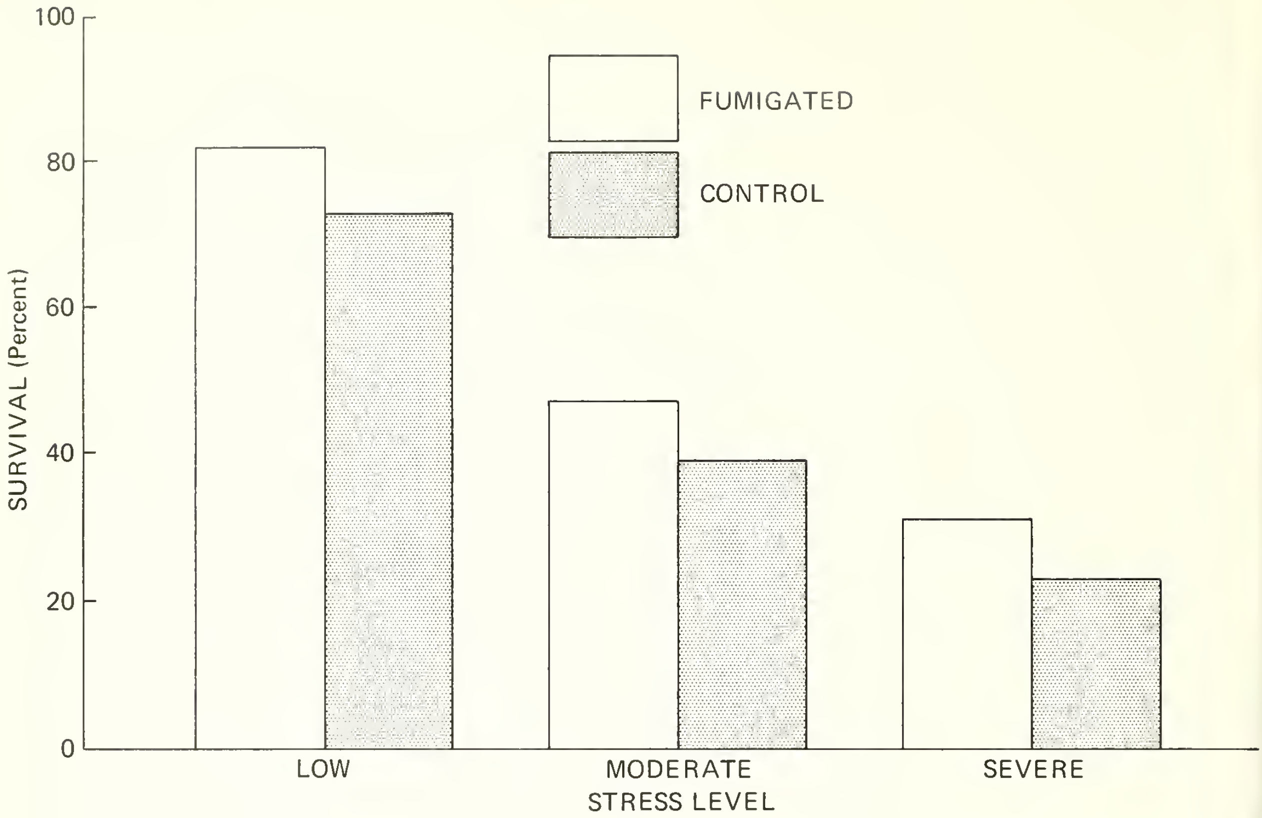

Figure 7.--Moisture-stress-plot survival of 2-0 Douglas-fir stock grown in fumigated and unfumigated seedbeds (survival as of September).

Effects of Seedbed Density

In one of the first applications of the stress plot technique, 2-0 ponderosa pine grown at various seedbed densities was planted and subjected to four stress levels. Results (fig. 4) show a positive effect of low density on survival at all stress levels. In this early trial, luxuriant growth of weeds in the low-stress plots probably caused a greater stress than was anticipated or desired. Ideally, the low-stress plot should serve more as a check on the ability of the trees to survive under favorable conditions than on the effects of the basic study variable on survival. In subsequent uses of the "Variable-Moisture-Stress-Plot" technique, the low-stress plot was kept completely weeded to reduce soil moisture depletion rates and the possibility of inadvertent stressing of test seedlings.

Effect of Antitranspirant Treatment

In this trial, the effects of a chemical antitranspirant, decynyl succinic acid, on survival of 2-0 Douglas-fir was tested at four stress levels. Under low and moderate stress, stock survival was uniformly high whether treated or not (fig. 5). Similar results might be expected in field tests conducted in years of abundant growing season precipitation. At high and severe stress levels, the chemical had a strongly inhibitory effect on survival. Thus, by testing under a wide range of stress, differences were found that would have gone undetected at low- or moderate-stress levels.

Effect of Different Age Classes

The desirability of periodic examination of trees in the stress plot for maximum information was demonstrated in tests comparing the survival of 2-1 and 3-0 Engelmann spruce (fig. 6). Late in the stress cycle, most of the trees had died; therefore no differences could be traced to age-class effects. However, midway through the stress cycle (July 15), obvious differences existed that demonstrated that the 2-1 stock had a superior survival potential. Without the timely examination at about the middle of the test period, this difference in survival capability would have gone unnoticed.

In another test to compare the effect of age class, both 1-0 and 2-0 stock of ponderosa pine and of Douglas-fir were planted at three stress levels. Survival of 1-0 and 2-0 ponderosa pine was not significantly different at any of the stress levels (99 vs. 98 percent, respectively, at low stress; 80 vs. 85 percent at moderate stress; and 47 vs. 54 percent at high stress). The survival of 1-0 Douglas-fir stock was significantly poorer than that of 2-0 stock at all stress levels (86 vs. 95 percent at low stress, 31 vs. 44 percent at moderate stress, and 5 vs. 18 percent at high stress). Subsequent field tests under a variety of field conditions using 1-0 and 2-0 stock of these species have verified the results of the "Variable-Moisture-Stress-Plot" tests.

Effects of Seedbed Fumigation

Planting stock of ponderosa pine, Douglas-fir, and western white pine grown in either fumigated or unfumigated soils have been "survival-tested" in the moisture-stress plots; results have been both positive and negative.[3] Douglas-fir stock grown in fumigated seedbeds survived and grew better under moderate and severe moisture stress than did stock taken from unfumigated beds (fig. 7). Survival of ponderosa pine grown in fumigated soil at one nursery was decreased by fumigation; at another nursery, there was a tendency (although statistically nonsignificant) for better survival of stock that had been grown in unfumigated soil. There was no evidence that white pine stock survival was affected by fumigation.

DISCUSSION AND CONCLUSIONS

Moisture-stress-plot evaluation of nursery stock performance has proven to be a valuable and efficient adjunct to field testing. The technique combines many of the best features of other systems. It is a direct approach, as is field testing, but it is quicker. It has many of the control features of the more indirect scientific techniques, but it is suitable for mass testing and broader inferences. Through continued use and experimentation, we hope to improve the system. We experienced greater variation in our test results than was anticipated, which probably resulted from fluctuations in stress caused either by (a) irrigation irregularities during the month or two preceding the start of the stress cycle, or (b) soil and weed competition differences within a given stress-level plot. Greater care during the pre-stress period and better control of competition might help reduce these variations and render the technique more sensitive statistically. If not, more replications (we generally used three) of test comparisons could be incorporated into the design.

It is virtually impossible to predict actual field survival or field survival differences from the results of this type of testing. The purpose of the technique is to determine whether potential survival or growth differences exist. If they do,

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[3] R. J. Boyd. Effects of soil fumigation on production of conifer nursery stock at two Northern Rocky Mountain nurseries. USDA Forest Serv. Res. Pap. INT-91, 19 p., illus. 1971.

the degree of moisture stress at which they become evident may indicate their relative importance when applied to field situations. Field-survival differences are so dependent on the natural variations in climatic conditions from year to year that a truly valid estimate of them would entail field testing for a number of years.

If treatment-caused survival differences are detected using the "Variable-Moisture-Stress-Plot" technique, the decisions regarding the use of nursery treatments should be made on the basis of cost, a fairly rough estimate of possible survival and growth differences, and other possible effects of the treatment. Should the results of a careful evaluation of the situation still leave the decision questionable--the possible consequences of a wrong decision are very costly--long-term field testing would probably be warranted before adopting a questionable practice.

☆ U.S. GOVERNMENT PRINTING OFFICE 1972-782 387/72 REGION NO

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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SDA Forest Service
esearch Note INT-166

November 1972

MODIFICATIONS AND TEST PROCEDURES FOR THE STOCKSTAD-LORY IGNITION FURNACE

Dwight S. Stockstad[1]

ABSTRACT

Ignition studies of such fine forest fuels as needles, rotten wood, and grass have been hindered by the lack of a suitable ignition-producing device and a reliable test procedure. Ignition tests were conducted at the Northern Forest Fire Laboratory on a variety of fuels. As a result of these tests, a standardized procedure was adopted and modifications were made to the Stockstad-Lory ignition furnace that overcame these difficulties.

A new ignition boat was designed and a stationary thermocouple was introduced for monitoring the ignition chamber temperatures. The test procedures adopted considered operator reaction time, introduction of the ignition boat in the isothermal ignition chamber atmosphere, the position of the pilot flame, and the effect of its introduction into the ignition chamber.

KEY WORDS: IGNITION, IGNITION FURNACE, FOREST FUEL IGNITION, PILOT IGNITION, SPONTANEOUS IGNITION.

The fire hazard associated with many forest and rangeland fuels is related to the gnitibility of the fine fuels. The Northern Forest Fire Laboratory Fuels Science esearch work unit developed a specially designed ignition furnace to study the gnitibility of these fuels.[2]

Ignition studies are hampered by the number of variables existing within any gnition-producing device and the selected test procedure, which makes securing a con-istent temperature relationship between the ignition furnace, the boat assembly, and he fuel particle difficult. These variables may be classed into three categories: 1) The fuel, (2) the furnace, and (3) the test procedure.

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[1]Research Forester in the Fuels Science research work unit at the Northern Forest ire Laboratory, Missoula, Montana.
[2]D. S. Stockstad and E. C. Lory. A forest fuel ignition furnace. USDA For. erv. Res. Note INT-122, 7 p., illus. 1970.

Variables like fuel size, shape, and moisture content can usually be controlled by the test operator. Chemical composition of the fuel particle may vary with location and time of collection[3] [4] but is assumed constant within a species collected from a given time and location.

The ignition furnace is a source of several variables. Some are controllable while others must be compensated for by adjusting testing procedures.

If a fuel particle is to be tested in an isothermal environment, this environment must have a similar temperature for each particle. The temperature of the furnace drops suddenly when the fuel particle and its holder are inserted into the furnace. This temperature drop can be assumed constant for all tests if the ignition boat and the fuel particle size are held constant. Introducing a pilot flame into the heated environment changes the temperature. (It also may be assumed constant for all tests if a given flame length and distance from the test sample are held constant.)

The results of ignition tests are affected by several operations in handling the sample. Variation of the cycle time between samples produces a corresponding variation in the furnace temperature and pattern of ignition. The time required to place thermocouples on the sample, load the sample onto the ignition boat, and insert the boat into the furnace all affect cycle time. Placement of the thermocouple on the sample and in the furnace must be carefully duplicated for each sample to obtain consistent results.

We developed a more feasible approach; that is, we assume the furnace temperature will change upon insertion of the sample, but this rate of change will be constant for all samples. The problem then becomes one of establishing a procedure to insure uniform temperature change rather than eliminating temperature change. This approach required minor modifications to the original furnace.[5]

FURNACE DESIGN MODIFICATIONS

The use of a thermocouple on the ignition boat assembly to measure ignition chamber temperature required an excessively long wait between tests for the mass of the boat to come to equilibrium with the ignition chamber. We eliminated this problem by installing a stationary thermocouple probe through the exhaust stack into the ignition chamber. This thermocouple was placed adjacent to thermocouples on the ignition boat assembly and positioned so all three thermocouples registered the same temperature when the system reached equilibrium (fig. 1). The stack thermocouple was then used to measure the control temperature for all tests.

[3]Charles W. Philpot and R. W. Mutch. The seasonal trends in moisture content, ether extractives, and energy of ponderosa pine and Douglas-fir needles. USDA For. Serv. Res. Pap. INT-102, 21 p., illus. 1971.

[4]Charles W. Philpot. Seasonal changes in heat content and ether extractive content of chamise. USDA For. Serv. Res. Pap. INT-61, 10 p., illus. 1969.

[5]See footnote 2.

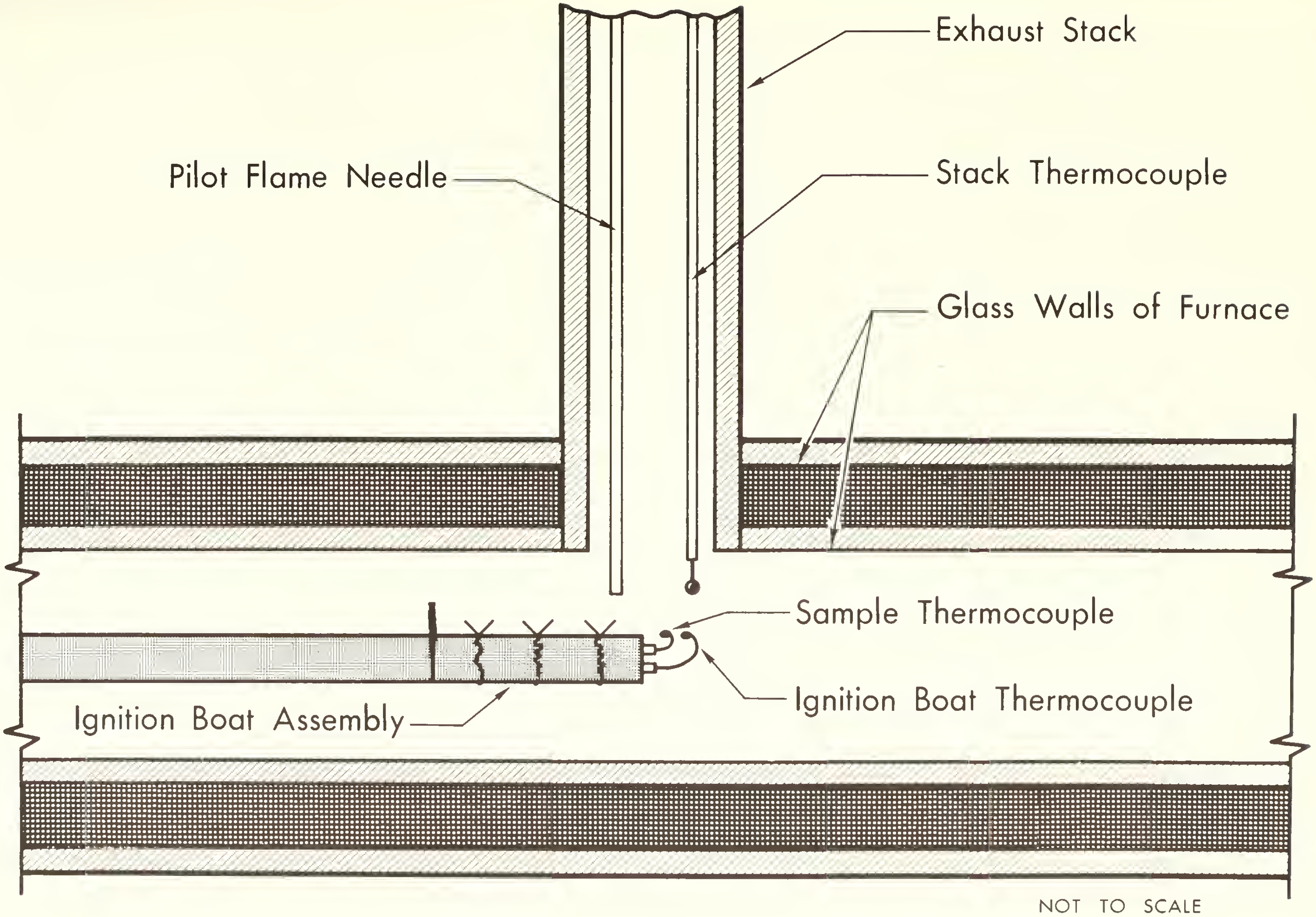

Figure 1.--Thermocouple placement in ignition chamber of Stockstad-Lory ignition furnace.

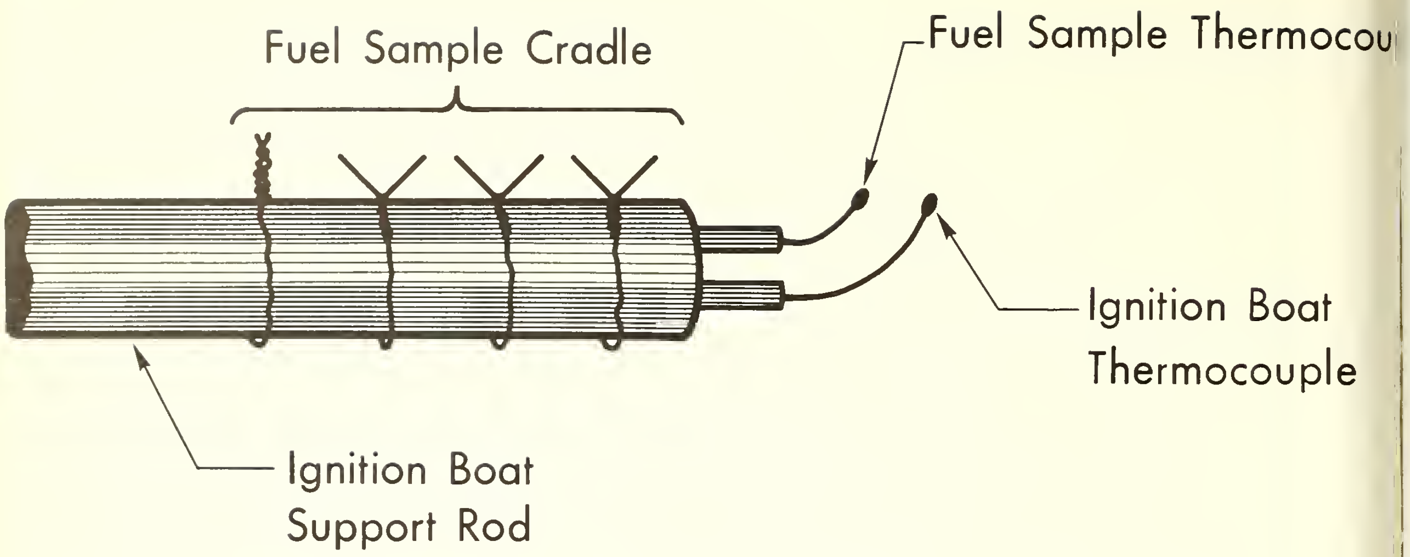

Figure 2.--Ignition boat assembly for Stockstad-Lory ignition furnace.

The clip-type ignition boat assembly was modified to provide a successful fuel particle holder for a variety of fuels (fig. 2). Number 28-gage thermocouple wire was used to form a cradle in which the fuel was placed. This cradle-type holder introduced less mass into the controlled temperature atmosphere.

TEST PROCEDURES

Procedures for spontaneous and pilot ignition tests were quite similar. The tests began with the ignition boat inside the furnace. The heating units of the furnace were adjusted to the desired temperature on the stack thermocouple and the ignition boat thermocouples. The ignition boat assembly was quickly withdrawn from the furnace. A fuel particle was placed on the holding cradle and immediately re-inserted into the furnace. Ignition time and temperatures were recorded and the stack thermocouple was monitored to determine when the ignition chamber had reattained the desired test temperature. The test cycle was then repeated.

The time required to withdraw the ignition boat, load the fuel particle, and reinsert the boat assembly were variables in this test procedure. But with experience, an operator can achieve a rhythmic motion and approach a constant value for all tests.

Pilot ignition tests followed the same sequence of procedures used in spontaneous testing except for a pilot flame in the ignition chamber. The effect of the flame on the ignition chamber temperature was determined by varying the distance between the tip of the 2-mm. pilot flame and the base reference point. The base reference was a 0.076- by 1-inch piece of metal rod placed on the ignition boat cradle. This metal rod had the same dimension as the fuel particles tested. The pilot flame length of 2 mm. was obtained by lowering the tip of the hypodermic needle on the pilot flame assembly until it touched the reference rod; the needle was backed off 2 mm. and the flame was adjusted to touch the reference rod.

The distance between the pilot flame and the reference rod was varied from 5 to 10 mm. Temperatures of the ignition chamber thermocouples were monitored for each position (fig. 3). The pilot flame raised the ignition chamber temperature by 9° C. in the 5-mm. position, and 0° at the 9- and 10-mm. positions.

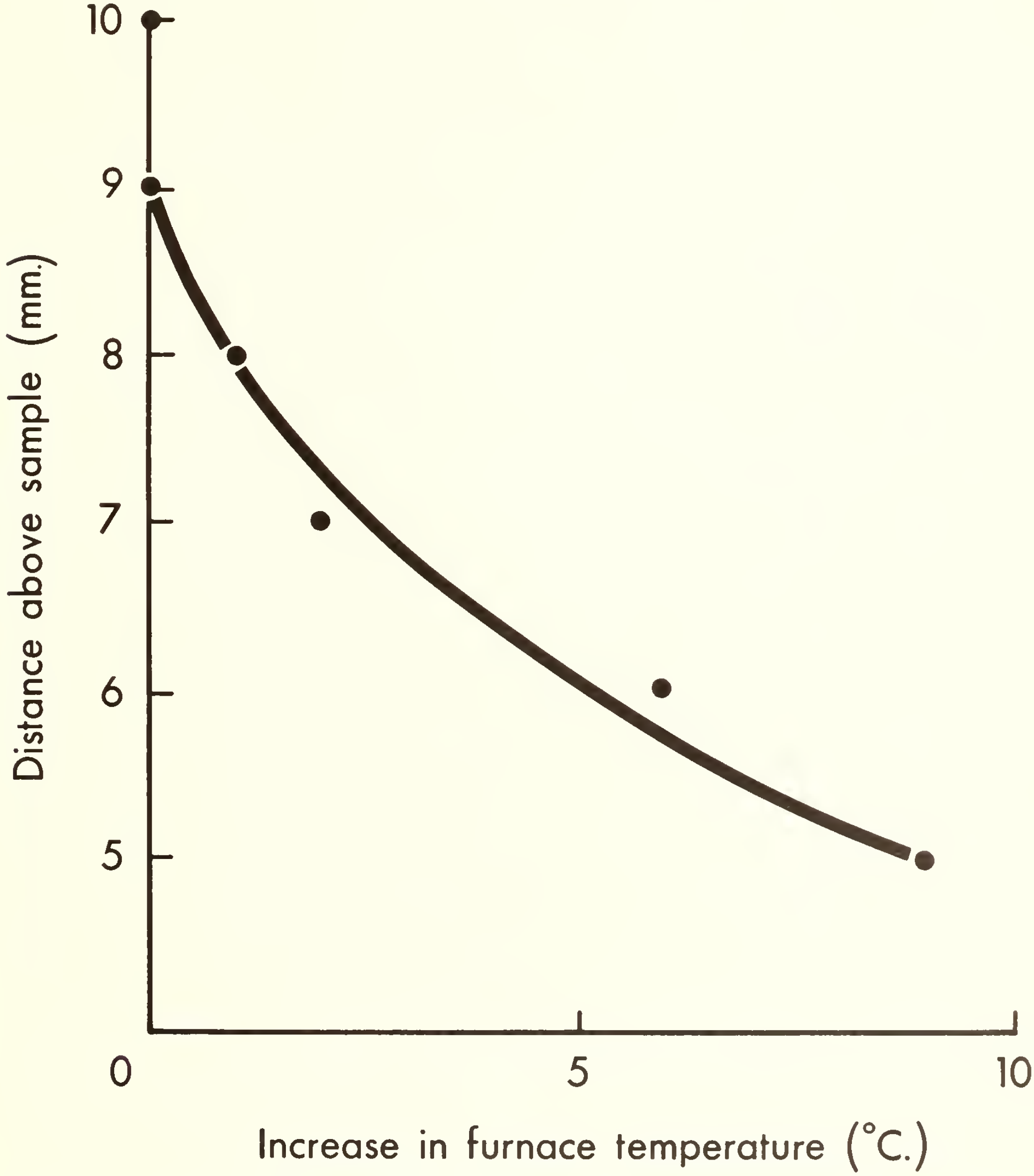

Figure 3.--Effect of pilot flame position on ignition chamber temperature in Stockstad-Lory ignition furnace.

The optimum position of the pilot flame for igniting volatiles from the samples was determined in a similar manner. The temperature of the ignition chamber was raised sufficiently to insure ignition of all samples if the volatile stream was in the proper concentration at the time of contact with the pilot flame. The position of the pilot flame was varied from no-sample ignition to 100-percent ignition (fig. 4).

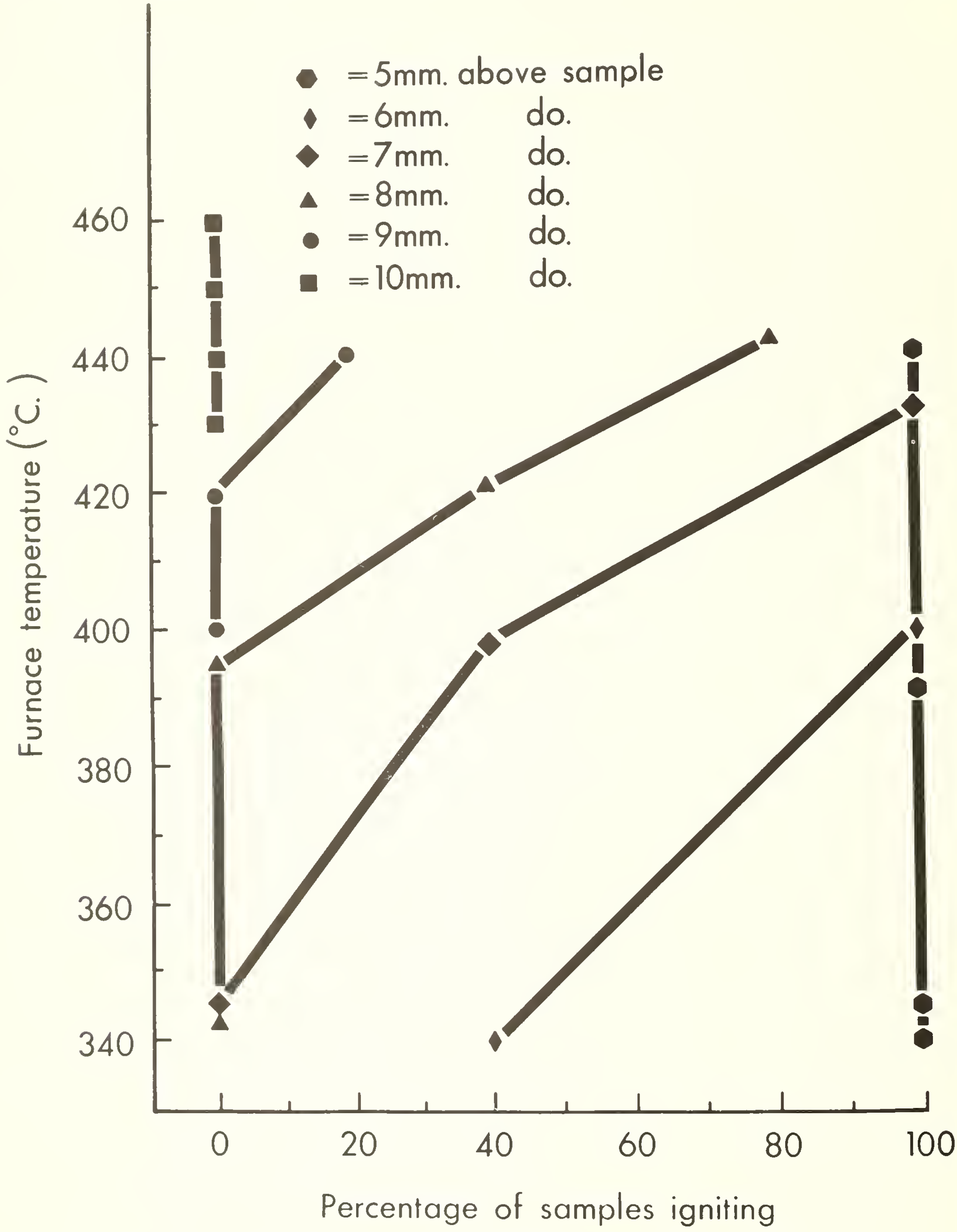

Figure 4.--Effect of pilot flame position on ignition process in Stockstad-Lory ignition furnace.

The maximum distance at which 100-percent ignitions occurred for all furnace temperatures tested was 5-1/2 mm. above the sample. No ignitions occurred at a position 10 mm. above the sample. Based on these results, the pilot flame was positioned 5-1/2 mm. above the test samples. This distance insured pilot ignition if the heat flux from the furnace was of sufficient magnitude and if volatiles from the sample were present in proper concentrations to support ignition.

Inasmuch as variation in sample size may necessitate a change in placement of pilot flame, fuels other than those we have tested (pine needles, cheatgrass stems, and rotten wood sections) may have a different pilot flame-to-sample relationship. As new fuels are tested, the procedure for optimum pilot flame placement should be followed. These tests are continuing at the Northern Forest Fire Laboratory.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972—782-467/79 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-167

April 1973

PERFORMANCE REQUIREMENTS FOR AIRBORNE INFRARED FOREST FIRE SURVEILLANCE EQUIPMENT

Forrest H. Madden[1]

ABSTRACT

Performance requirements for a real-time recording, bispectral, line-scanning infrared equipment are outlined for application to forest fire detection and mapping.

OXFORD: 432.23; 587.3.
KEYWORDS: Aerial fire detection; Aerial mapping; Remote sensing; Fire surveillance; Infrared scanning.

This document delineates requirements for airborne infrared (IR) forest fire surveillance equipment (FFSE) capable of detecting and indicating the locations of small latent-stage forest fires and accurately mapping terrain details to establish the perimeters of large forest fires.

An airborne IR forest fire surveillance system must:

1. Detect a small, latent-stage forest fire in the presence of background temperature extremes;[2]

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[1]Electronic Engineer, stationed in Missoula, Montana, at Northern Forest Fire Laboratory.

[2]Ralph A. Wilson, S. N. Hirsch, B. J. Losensky, and F. H. Madden. Airborne infrared forest fire detection system: final report, p. 17. USDA For. Serv. Res. Pap. INT-93, 99 p., 1971.

2. Present information in such a way that a photointerpreter can accurately locate the fire;

3. Patrol large areas;[3]

4. Locate small spot fires adjacent to a large fire;[4]

5. Image large fires in such a way that fire perimeters, including smoldering edges and flaming fronts, can be accurately established;[5]

6. Locate small, hot fires within a large burned area during mop-up operations;[6]

7. Make near real-time, quality imagery of the area traversed for navigation; for in-flight interpretation of fire location; and for fire camp interpretation of a large fire's progress and of dangerous areas (e.g., unburned areas within the fire, spot fires, major fuel changes, and the fire's relationship to high-value areas).[7]

The above criteria indicate a need for fire-detection equipment that quickly detects and locates small, latent-stage fires while surveying large forested areas, and for fire-mapping equipment that provides good background detail (e.g., roads, firelines, and fuel breaks to the nearest 50 feet[8] outside the fire perimeter.)

Fire detection requires a fast aircraft at high altitudes; fire mapping usually calls for a slower plane at lower altitudes. The type of aircraft and its operation determine which mission is to be performed. However, similar requirements for locating small, lightning-caused fires and small hot spots near the perimeter of a large fire help define standardized fire detection/fire mapping equipment.

While covering a search area at a rate of at least 2,000 square miles per hour from 15,000 feet above terrain with backgrounds ranging from 0° to 50° C., operational equipment must detect (with nearly 100 percent probability) every unobscured, 1-square-foot, 600° C. fire.[9] Of equal importance, image quality must be sufficient to permit interpretation of fire location to the nearest 40 acres.

While covering a large fire at a rate as low as 150 square miles per hour, operational equipment must image large fires without distortion on the imagery adjacent to hot areas so that the fire perimeter, including smoldering edges and flaming fronts, can be located to the nearest 50 feet.

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[3] Ibid.

[4] Stanley, N. Hirsch, Robert L. Bjornsen, Forrest H. Madden, and Ralph A. Wilson. Project Fire Scan fire mapping final report, April 1962 to December 1966, p. 33. USDA For. Serv. Res. Pap. INT-49, 49 p., illus., 1968.

[5] Ibid.

[6] Ibid.

[7] Stanley N. Nirsch. The scope of remote sensing applications to forest fire control. *In* Workbook for Remote Sensing for Forest Fire Control Seminars, Spring 1971. Copies on file at Northern Forest Fire Laboratory, Drawer G, Missoula, Montana 59801.

[8] A compromise by the author from private conversations with Fire Scan personnel and Division of Fire Control personnel whose estimates range from 20 to 100 feet.

[9] An emissivity approximately equal to 1 is assumed.

From these requirements, a figure of merit (N) can be established for an IR FFSE:

$$N = \frac{\sqrt{\text{area scanned/unit time}}}{\text{temperature sensitivity} \cdot (\text{angular resolution})^2}$$

$$= \frac{\sqrt{\dfrac{\text{TFOV}}{(\text{IFOV})^2} \cdot \dfrac{V}{H}}}{(\Delta T)\ (\text{IFOV})} \geq 0.322$$

where:

TFOV = total field of view in radians
V/H = velocity-to-height ratio of equipment in radians/second
IFOV = angular resolution in milliradians (mrd)
ΔT = temperature sensitivity in °C.

DEFINITIONS

Small forest fire	For this specification, at least 1 square foot of hot burning material (600° C.) that does not meet the requirements of a large forest fire.
Large forest fire	Any fire that has escaped initial suppression forces and requires additional manpower to contain.
Spot fire	Similar to the small forest fire, but near a large forest fire.
Background	All objects within a surveillance area that have radiometric temperatures of 50° C. or less. Other signals normally considered as background (e.g., solar reflections from buildings or water, geysers, and hot highways) are excluded and must be taken into account when targets are interpreted.
Gray scale	Defined as $1/\sqrt{2}$ times density from the maximum density to fog level of the image medium.

IR FFSE PERFORMANCE REQUIREMENTS

A near real-time, line-scanned, contiguous and continuous in-flight thermal processed image of the terrain traversed must be produced and all fire targets superimposed on the thermal background image.[10] Figure 1 is a block diagram of an existing system doing this job.

[10]Stanley N. Hirsch. Application of infrared scanners to forest fire detection. Int. Workshop Earth Resourc. Surv. Syst. Proc., Vol. 2:153-169, illus., 1971.

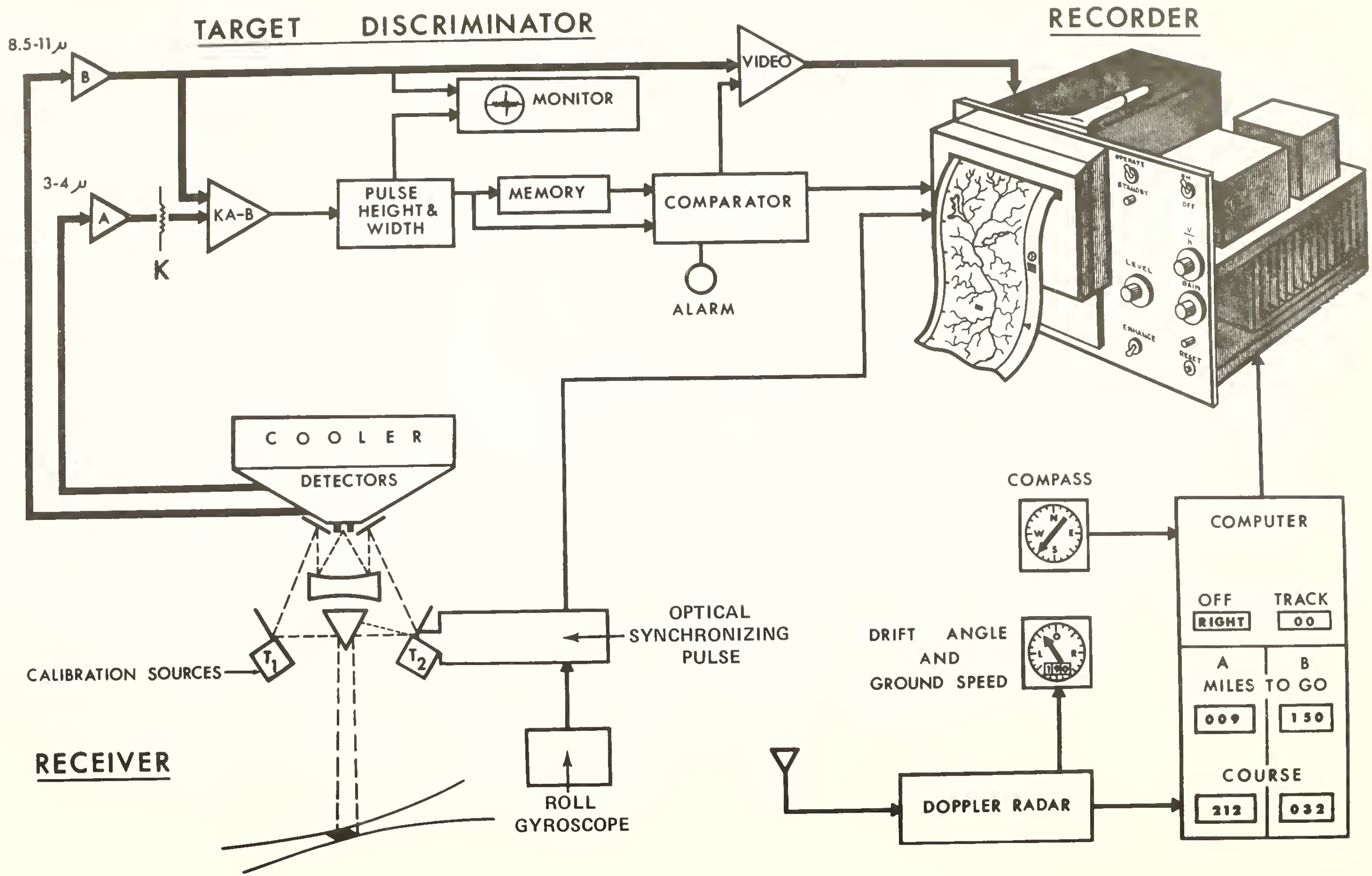

Figure 1.--Infrared fire surveillance prototype equipment block diagram.

Equipment Modulation Transfer Function (MTF)

The transfer function for the FFSE is defined as a function that relates image density in gray scales and a range of background temperatures in degrees centigrade (°C.) to the angular resolution or sampling rate. Three points on the MTF curve near the high resolution (fast sampling) limit of the system are defined as minimum: 85 percent modulation at 4 mrd IFOV; 50 percent modulation at 2 mrd IFOV; and 10 percent modulation at 1 mrd IFOV. The low resolution end of the MTF curve is direct coupled to insure a stability that results in less than 1-gray scale drift on the image for every hour of operation.

Target Discrimination

The success of an FFSE depends entirely upon its ability to locate and mark small fire targets on the imagery. The FFSE must discriminate and mark small fire targets with a radiometric power of 1/10, the maximum background variation, on the imagery and at the same time reduce false alarms to near zero. Discrimination of small targets is based on spectral discrimination at two radiometric wavelengths (see fig. 1): spectral band A has a wavelength near the peak power of a 1,000° K. fire; spectral band B has a wavelength near the peak of the background power (300° K.).

In addition to spectral discrimination, scan-to-scan and time correlation is used to eliminate spurious aircraft noise, navigation pulses, and external radar signals that have time durations less than four times the IFOV.

Temperature Sensitivity

Bispectral (two independent spectral channels) equipment images one channel with background temperature sensitivities of 1/2° C. or less when adjacent to 1,000° K. sources and maintains a good signal-to-noise ratio in the nonimaged channel. For optimum performance, the two channels must be matched to changes in atmospheric moisture from 1/2 to 2 cm. of precipitable water in the path length.

Total Field of View (TFOV)

A 120° active scan (±60° nadir) along with ±10° roll correction, a total unvignetted scan of 140°, is required.

Radiometric Calibration Sources

Two thermal calibration sources are used. Each fills the total scan aperture at different times during the scanner dead time; so the two extremes of normal background temperatures experienced in a forested background are covered. Temperature ranges recommended are from 0° to 20° C. (T_1) for one source and 35° to 55° C. (T_2) for the second, figure 1.

Velocity-to-Height Ratio (V/H)

A scanner V/H of at least 0.2 radian/second gives the 2:1 overscan required for target discrimination with a maximum aircraft V/H of 100 knots/1,000 feet. Higher scanner V/H's permitting more overscan are permissible.

Roll Stabilization

Roll stabilization must meet the requirements in each applicable aircraft. Roll stabilization over a ±10° range is required over the TFOV.

Slant Range Correction

Slant range correction (rectilinearization) corrects for changes in aspect ratio from nadir to the edge of the scan. Ground distances measured on the image from nadir to ±50° must be linear to within 2 percent. The average density caused by slant range correction must not vary more than 1 gray scale across the image perpendicular to the line of flight.

Permanent Record

The method used to record data can improve the fire surveillance system's operation or preclude its use. Fire surveillance requires a photographic-quality image processed in the aircraft within minutes after the plane has passed over a given area. The type of photographic material used to record the image can also enhance or limit the equipment's capability. Material (and equipment to print the material) must be carefully selected.

Spectral band B signals are used to make a printed image at least 8 inches wide. The hot target marker, derived from the spectral and time correlation of the signals from spectral bands A and B, is inserted into the printing video to mark all fire targets on the imagery for easier identification. A fiducial mark in the margin of the image is alined with the hot target marker for easier target location.

Mileage marks, derived from the navigation system, mark the margin of the imagery to indicate the relative number of miles traveled. Annotation in the margin of the image clearly identifies the mission by number, date, time, and location.

Target Alarm

A fire target alarm maintains a visual indication of a hot target until the operator manually resets it.

Monitors

The FFSE must contain an equipment monitoring oscilloscope to calibrate the spectral discrimination signals, to evaluate signal quality during image flights, and to detect and locate equipment failure in flight and on the ground.

Environment

The FFSE must meet all environmental requirements normally applied to any given installation in an aircraft. For example, temperatures can vary from -40° C. at high altitudes to +55° C. on hot runways. Shock and vibration should be within normal limits for manned aircraft.

AIRCRAFT PERFORMANCE REQUIREMENTS

The performance of the aircraft for infrared fire surveillance determines whether the system is capable of only fire mapping, fire detection, or both. Certain performance requirements, which are listed below, can limit the operation. The lower performance requirements cited are applicable to fire mapping, whereas the higher performance requirements are desirable for fire detection. The minimum requirements needed to accomplish both missions are listed in the normal range column that follows. Doppler or inertial navigation system is required in both cases.

	Lower	*Normal range*	*Higher*
1. Altitude over terrain (feet)	500	2,000/25,000	50,000
2. Range (nautical miles)	1,000	1,200	3,000
3. Speed (knots)	50	85/250	600
4. Equipment weight (less crew, pounds)	[11]600	[11]750	[11]1,000
5. Pilot and aircrew (number)	2	2	3

The complete "Performance Requirements and Technical Specifications for Airborne Infrared Forest Fire Surveillance Equipment" will be prepared at the Northern Forest Fire Laboratory and held for those who need a complete specification of the infrared system.

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[11]Includes auxiliary equipment such as the navigation system, vertical gyro, and power inverter.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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USDA Forest Service
Research Note INT-168

June 1973

A COMPARISON OF SPRUCE BUDWORM POPULATION ESTIMATES BETWEEN SOUTHERN IDAHO AND EASTERN OREGON

Walter E. Cole, Research Entomologist

ABSTRACT

Two relationships--prediction of immature budworm larval populations based on the pupal case population of the previous year and estimates of final defoliation severity based on the immature larval populations of the same year--are developed for southern Idaho by regression analysis and compared to the same relationships developed in eastern Oregon.

OXFORD: 153--015.5:416.11.
KEYWORDS: population, defoliation damage (estimates), budworm.

A recently initiated cooperative program on western spruce budworm populations has brought about an awareness of a need for more information on population measurements. Consequently, it would seem appropriate and timely that results from a study I made during 1958-1960 should be documented as background information to a recent publication by Carolin and Coulter.[1] My study primarily was concerned with the measuring of budworm population levels and subsequent extent and severity of defoliation.

Ten trees from each of three plots were sampled for 3 years. Four 15-inch twigs per tree--one terminal and three laterals--were used to sample larvae, pupae, and foliage. The early larvae were sampled after approximately 50 percent had emerged from hibernation and had mined buds or needles. Pupae were sampled when approximately 50 percent of the larvae had emerged.

Seasonal defoliation was based on the number of damaged buds (new growth tips) found on the twigs, which were classed according to percent of the needles destroyed per bud as follows: (1) 90 percent or more; (2) 75-90 percent; (3) 50-75 percent; (4) 25-50 percent; (5) less than 25 percent; and (6) residual undamaged buds.

[1]V. M. Carolin and W. K. Coulter. Sampling populations of western spruce budworm and predictive defoliation on Douglas-fir in eastern Oregon. USDA For. Serv. Res. Pap. PNW-149, 38 p. 1972.

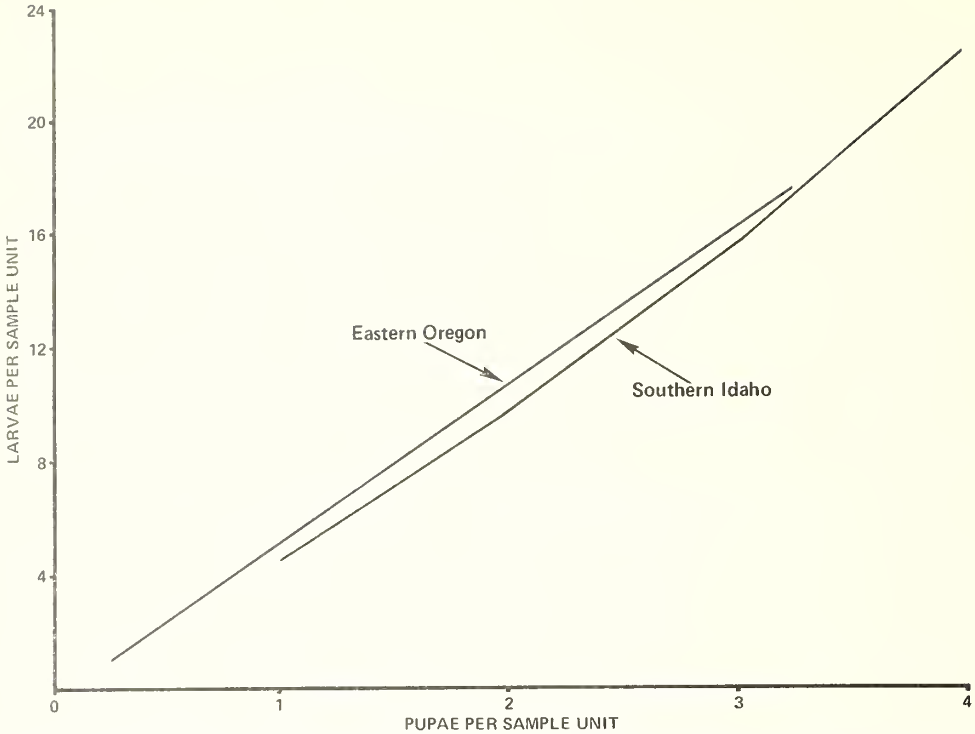

Figure 1.--Linear regression of larval density on pupal density (southern Idaho based on larvae per 15-inch twig; eastern Oregon based on larvae per 100 15-inch twigs).

During the 3 years of my study there was no significant difference between years in the early larval populations per twig, in the late larval populations per twig, and in reduction of larval numbers between early and late populations.[2] In other words, the populations approximated each other among plots each year and within each plot during the study period. Consequently, the data were pooled over the 3-year period.

The regression of immature larval populations on pupal case populations was determined to be

$$\text{Log } (y + 1) = 0.27 + 1.57 [\text{Log } (x + 1)] \quad (r = 0.75)$$

where

y = expected number of immature larvae per 15-inch twig

x = number of emerged pupal cases per 15-inch twig.

Figure 1 shows the comparison of my regression to Carolin and Coulter's regression which was

$$y = -62.6 + 5.608x \quad (r = 0.81).$$

However, Carolin and Coulter's regression was based on nontransformed data; furthermore, their sample unit was 100 15-inch twigs.

[2]Based on a 90 percent confidence level. (Data were transformed using $y = \log_{10} (x + 1)$ because budworm larval populations follow the negative binomial distribution.)

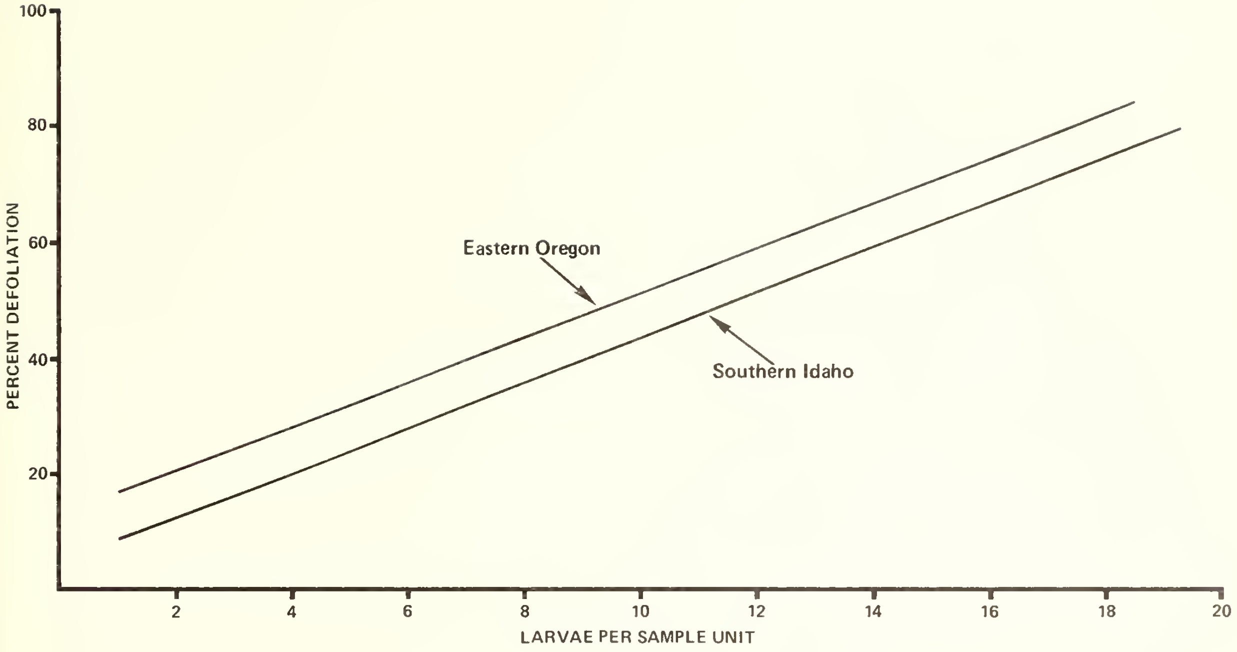

Figure 2.--Linear regression of defoliation of current growth on larval density (southern Idaho based on larvae per 15-inch twig; eastern Oregon based on larvae per 100 15-inch twigs).

My regression of ultimate defoliation on immature larval populations per 15-inch twig was

$$y = 5.17 + 3.8x \quad (r = 0.69).$$

Again, their regression was based on a 100 15-inch twig sample. Figure 2 shows a comparison of my regression with Carolin and Coulter's regression:

$$y = 12.84 + 0.038x \quad (r = 0.88)$$

Caution should be used in basing a prediction on pupal cases, particularly within a highly fluctuating population or when the time to sample is based on 50 percent emergence. Carolin and Coulter used 75 to 90 percent emergence; this possibly explains the difference between their regression estimates and mine. Also, differences between their regression estimates and mine for defoliation could be attributed to differences in sampling techniques. However, these differences are only evident in degree; our slopes of regression are parallel. Therefore, a reasonable estimate of desired populations can be made using a 4-twig sample; precision of such an estimate can be improved using a 100-twig sample.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-169

June 1973

AN 18-KT. GOLD SPHERE GIVES ACCURATE HEAT FLUX DATA

Dwight S. Stockstad[1]

ABSTRACT

Describes construction details of a specially designed instrument for measuring heat flux in a laboratory ignition furnace. An 18-kt. gold sphere was used as the sensing element for this instrument. Also gives results of tests to determine reliability of such a sphere for measuring convective and radiative heat flux.

OXFORD: 431.5: U536.2
KEYWORDS: ignitibility (forest fuel), heat transfer, heat flux sensor, gold sphere heat flux sensor, ignition furnace

Several methods have been developed to measure radiant and convective heat transfer of heating systems used in combustion studies (Joint Fire Research Organization 1965; McCarter and Broido 1966; Waterman 1968). Most of these compared the heat absorption of a highly reflective surface as opposed to that of a highly absorptive surface. Although such methods do have certain limitations, as discussed by Waterman (1968), they were deemed suitable for application to an ignition-producing furnace we had developed for our forest fuel ignition studies (fig. 1) (Stockstad and Lory 1970; Stockstad 1972).

The small diameter of the ignition chamber (45 mm.) of the furnace dictated the use of a slender rod to carry the sensing element. As a result, we had to design a probelike instrument (shown in fig. 2) the size and weight of which is intended to minimize fluctuations in furnace temperatures as it is inserted into the chamber.

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[1]Research Forester, stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

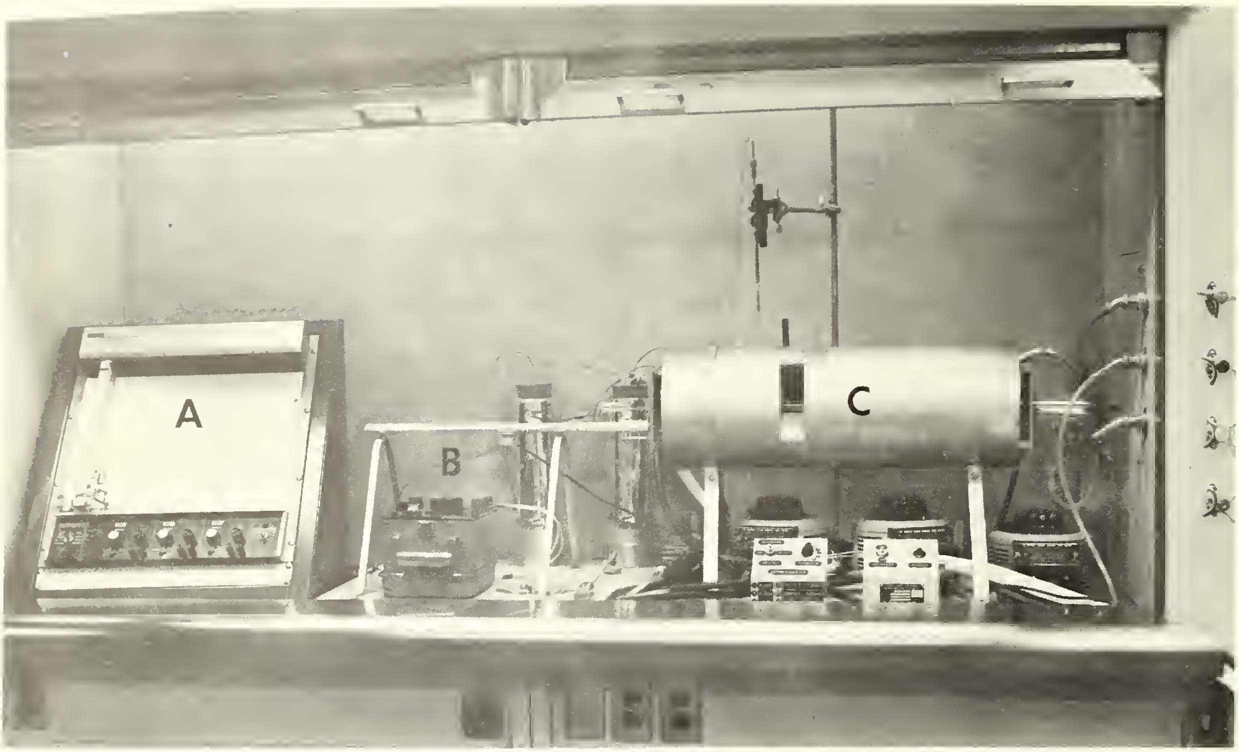


Figure 1.--Experimental furnace assembly consisting of: A, three-channel recorder; B, slide assembly; and C, ignition furnace.

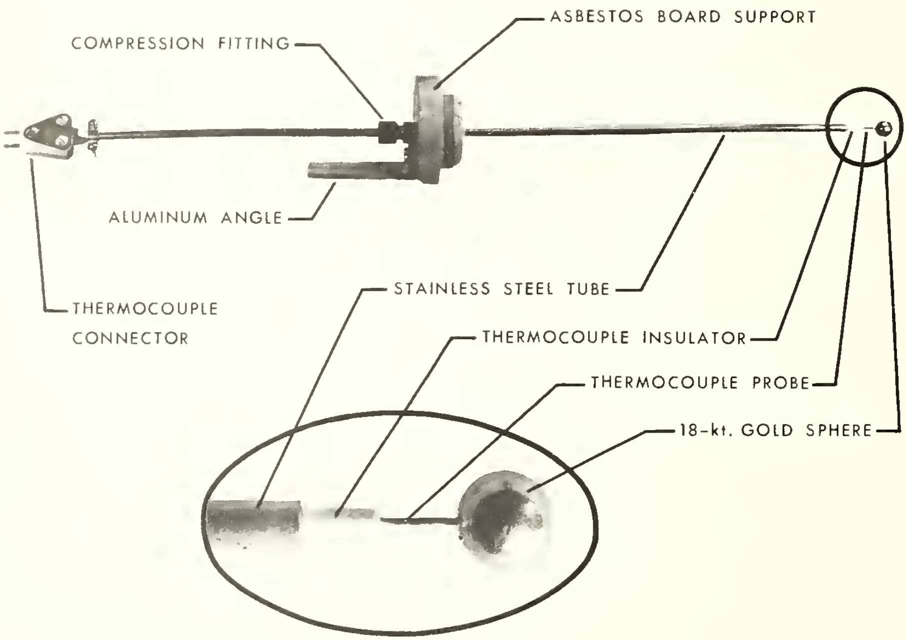


Figure 2.--An 18-kt. gold sphere sensing probe for measuring heat flux.

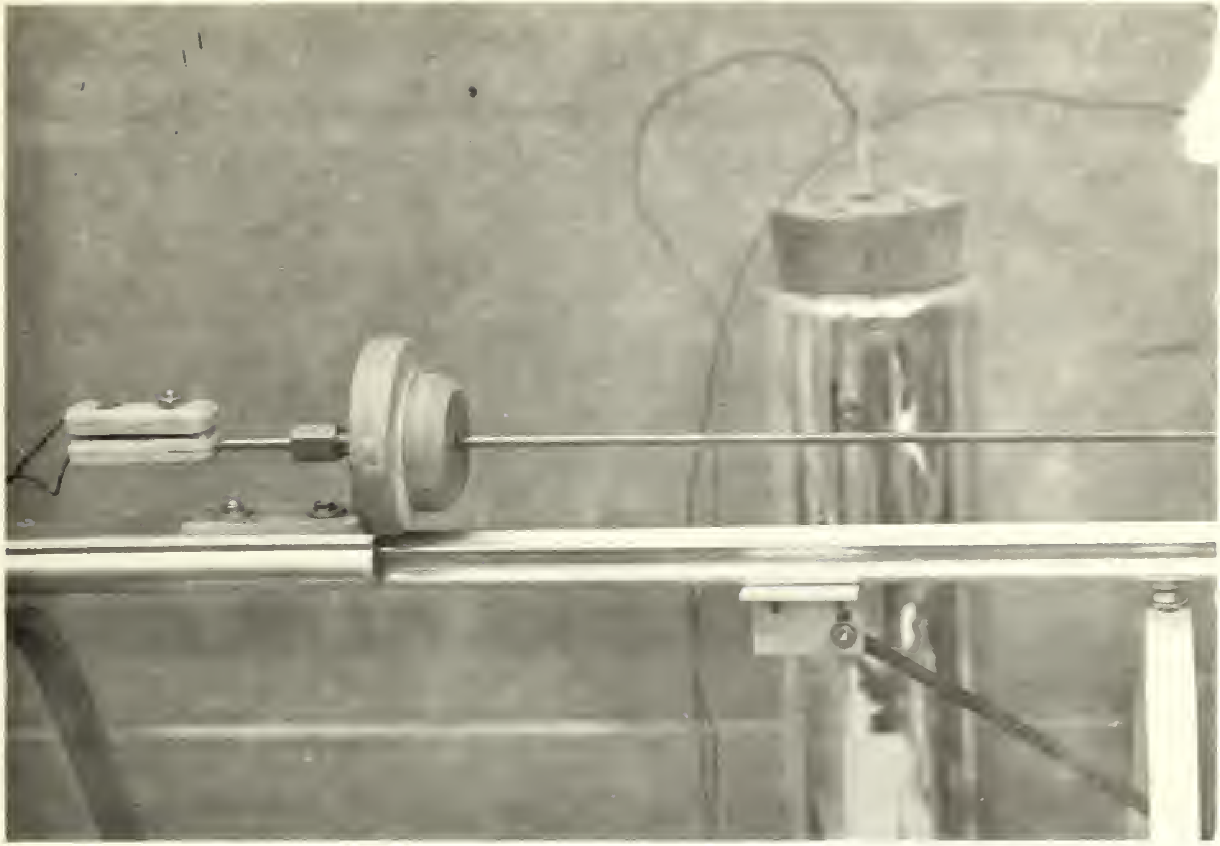


Figure 3.--Heat flux sensing probe attached to slide mechanism of furnace.

CONSTRUCTION DETAILS

The sensing element was cast from 18-kt. gold using a 0.380-inch steel ball as a pattern for the mold. The resulting sphere was 0.385 ±0.002 inch in diameter. The sphere was center drilled on a jeweler's lathe to provide a recess for the thermocouple.

The thermocouple was a grounded junction, chromel-alumel type encased in stainless steel. The gold sphere was heated and attached to the thermocouple sheath which had been refrigerated. This insured a tight fit. The thermocouple then was inserted into a ceramic insulator and placed in a stainless steel tube.

A plug was made for the ignition chamber using 1/2-inch asbestos board. A compression fitting was attached to this plug to support the probe and permit adjustment of the sensing element within the furnace. An aluminum angle was used to attach the probe to the slide mechanism of the furnace (fig. 3). The base of the angle was drilled with slotted holes to provide the horizontal adjustment of the probe within the furnace.

PREDICTION OF RESULTS

Calculations were made to predict the theoretical time-temperature curves of the spheres when inserted into a known temperature environment. Calculations were made for both polished and blackened gold spheres. The following assumptions were made for these calculations: Ignition chamber temperature = 417° C. (783° F.) and volume of laboratory air at ambient conditions = 5 liters/minute.

Four dimensionless numbers were used in the calculations:

Nusselt Number - $N_u = \frac{hd}{K}$

Reynolds Number - $N_{Re} = \frac{du}{\lambda}$

Biot Number - $N_{Bi} = \frac{hr_1}{K}$

Fourier Number - $N_{Fo} = \frac{\alpha\tau}{r_1^2}$

where

h = heat transfer coefficient
d = diameter of gold sphere = 0.385 inch
K = thermal conductivity (air in Nusselt Number and gold in Biot Number)
u = velocity of air in ignition chamber = 0.48 ft./sec.
λ = kinematic viscosity of air
r_1 = radius of gold sphere = 0.192 inch
α = thermal diffusivity of gold (assumed to be 1.00 for the blackened sphere and less than 0.035 for the polished sphere)
τ = time since insertion of probe (seconds).

The Nusselt Number was obtained using McAdams' chart (1954, page 266), after the Reynolds Number had been calculated for the assumed conditions. The convective heat transfer coefficient then was calculated from

$$h = \frac{KN_u}{d}$$

The radiation heat transfer coefficient was calculated from

$$h_r = \frac{I_R}{t_f - t_{ambient}}$$

where

$I_R = \sigma\varepsilon T^4$

and where

ε (of furnace wall) was assumed to be 1.00

and where

$\sigma = 1.714 \times 10^{-9}$ ft.^{2}/sec.

t_f = furnace temperature in °F.

$t_{ambient}$ = ambient temperature in °F.

T = furnace temperature in °Rankine.

The convective and radiation heat transfer coefficients were summed to determine the total heat transfer coefficient which was used to calculate the Biot Number. Values were then assumed for the product of $N_{Fo} \times N_{Bi}$ and the equation solved for τ. Giedt's chart (1957, page 311) was used to obtain values for θ (a dimensionless temperature ratio),

where

$$\theta = \frac{t_o - t_f}{t_i - t_f}$$

and where

t_o = temperature at time τ at center of sphere

t_i = initial temperature of sphere center

t_f = air temperature of ignition chamber.

The equations for θ were solved for t_o and the results tabulated with corresponding values for τ (see tables 1 and 2 and figures 4 through 7).

Table 1.--*Predicted and recorded temperatures for the polished gold sphere*

Time (minutes)	Temperature of gold sphere: Predicted in airflow of 5 ℓ./min.	Recorded in airflow of 5 ℓ./min.: Mean	Maximum	Minimum	Recorded in nitrogen flow of 5 ℓ./min.: Mean	Maximum	Minimum
	- - - - - - - - - - - - - - - - - °F. -						
1.12	263	265	273	260	252	252	252
2.25	396	400	417	386	386	386	386
4.50	572	580	588	572	559	559	559
6.75	666	684	693	666	658	658	658
9.00	713	745	756	713	718	718	718
11.20	748	774	791	748	748	748	748
16.90	781	781	786	770	778	778	778
Furnace temperature:							
	783	778	786	770	788	788	788

Table 2.--*Predicted and recorded temperatures for the blackened gold sphere*

Time (minutes)	Temperature of gold sphere: Predicted in airflow of 5 ℓ./min.	Recorded in airflow of 5 ℓ./min.: Mean	Maximum	Minimum	Recorded in nitrogen flow of 5 ℓ./min.: Mean	Maximum	Minimum
	- - - - - - - -	- - - - -	- - - - °F.	- - - - -	- - - - -	- - - - -	- - - - -
0.38	263	253	260	249	250	250	250
0.76	396	359	386	341	364	364	364
1.52	572	539	572	520	537	541	532
2.28	666	644	680	624	645	649	641
3.05	713	711	743	692	710	714	705
3.82	748	735	769	714	740	740	740
5.71	781	768	784	748	769	769	769
Furnace temperature:							
	783	779	786	775	788	788	788

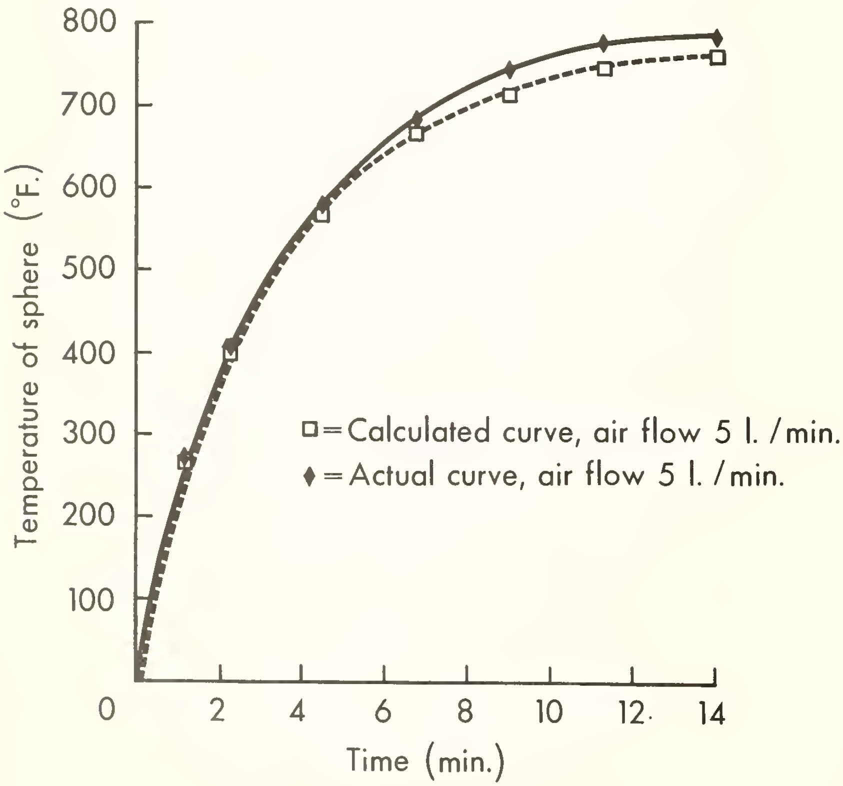


Figure 4.--A comparison of predicted and recorded temperatures for the polished sphere in an air atmosphere.

Figure 5.--A comparison of predicted and recorded temperatures for the polished sphere in a nitrogen atmosphere.

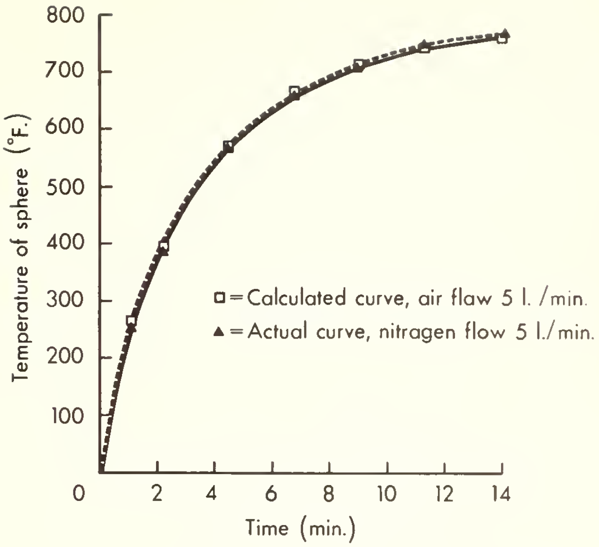


Figure 6.--A comparison of predicted and recorded temperatures for the blackened sphere in an air atmosphere.

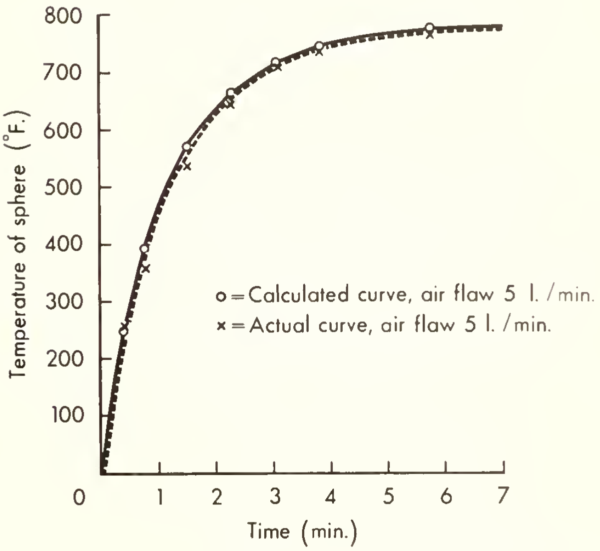
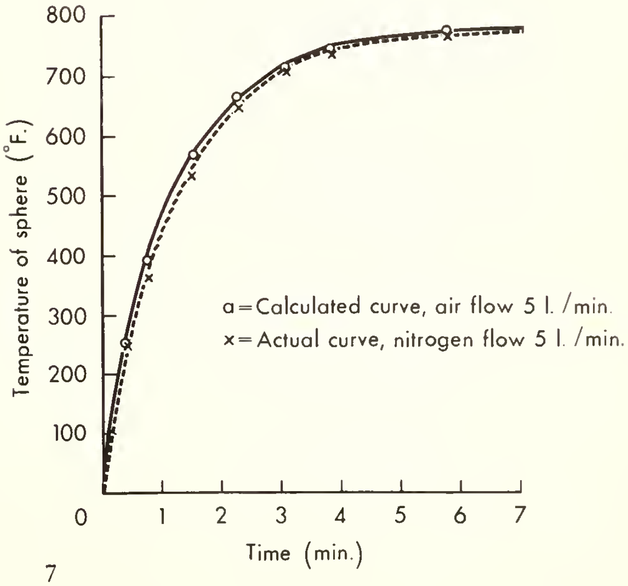


Figure 7.--A comparison of predicted and recorded temperatures for the blackened sphere in a nitrogen atmosphere.



TEST PROCEDURES AND RESULTS

The gold spheres on two identical sensing probes were polished and tested at various furnace temperatures before the heat flux determinations were made. Data from these tests indicated the gold spheres were similar in response characteristics and could be used interchangeably.

Each of the 20 heat flux determinations was begun when the temperature of the ignition chamber reached 783° ±15° F. (All except two were within ±8° F.). These determinations were made by inserting the sensing probe in the ignition chamber and recording the time-temperature curve.

Five tests were made using the blackened spheres and five using the polished spheres in both air and nitrogen atmospheres. In the air atmosphere, the polished spheres turned almost completely black which undoubtedly was attributable to the alloys in the gold. This produced a gradual increase in the sphere's absorption of the radiation flux, which was verified by higher temperatures being recorded for the polished sphere than had been predicted (fig. 4). To eliminate this problem, the atmosphere within the ignition chamber was changed from air to nitrogen. As a result, the recorded temperatures were nearly identical to the predicted temperatures (fig. 5). The predicted and recorded temperatures for the blackened spheres in both air and nitrogen atmospheres also were in almost complete agreement. In both instances we attributed the slight differences to the degree of resolution of the experimental apparatus.

CONCLUSIONS AND DISCUSSION

The close agreement of the actual test results and the predicted results indicates that the use of 18-kt. gold spheres is reliable for measuring the heat flux components of a laboratory ignition furnace. This method may be adopted by other scientists engaged in ignition research to insure comparable results.

This method already has been used in fuel ignition studies involving yellow pine *(Pinus ponderosa)* needle sections, cheatgrass *(Bromus tectorum)* stem sections, and sections of rotten wood. It also will be used to document heat flux of a strictly convective heat furnace for use in studies of crowning potential and firebrand formation of various forest fuels.

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U.S. GOVERNMENT PRINTING OFFICE: 1973 — 784-293 / 3 REGION NO. 8

Research Note
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-170 June 1973

INTERACTION BETWEEN MOUNTAIN PINE BEETLE AND DYNAMICS OF LODGEPOLE PINE STANDS

Walter E. Cole, Research Entomologist

ABSTRACT

The influences of habitat types, diameter classes, and phloem thickness on beetle populations and the reverse, the influence of beetle populations on stand dynamics, form a coordinated interrelationship within the lodgepole pine ecosystem. The loss of trees to mountain pine beetles is partly a function of stand structure. Beetle population survival may be dependent upon either food supply or elevation, according to the particular habitat involved. This type of information can be used to estimate the probability of tree loss, risk of infestation, and brood survival.

The mountain pine beetle is a native pest exerting numerous and various effects upon the lodgepole pine ecosystem. Historically, the mountain pine beetle has infested large areas of lodgepole pine; within the Intermountain region, it has depleted these stands by periodically killing the largest, most vigorous trees. One of the primary problems of managing lodgepole pine is this ever-present beetle pressure and recurring mortality. In order to provide the timber manager with alternatives for lodgepole pine, it is first necessary to develop an understanding of the life processes within the beetle population and between the beetle and its host tree.

Our ongoing research of mountain pine beetles in the lodgepole pine ecosystem is to develop knowledge having wide application in bark beetle pest problems. Hopefully, these results, ideas, and principles also can be applied to bark beetle problems within other ecosystems.

The loss of trees to the mountain pine beetle is partly the function of stand structure within different habitat types. Stand tables have been constructed for infested trees. These tables are based on phloem thickness, distribution, and frequency of trees of discrete specific diameters within the different habitat types. From these tables, simulated infestations and also the probability of lodgepole pine survival by prescribed diameters for the period of infestation have been constructed.

In our studies, beetle populations in lodgepole pine have been sampled to determine biological and behavioral relationships between the beetle and its food, habitat, and associates. Factors measured include (a) crowding during the larval development, (b) attack density of the adults, (c) elevation of infested stands, (d) size and distribution of trees within stands, (e) habitat types, (f) parasites and predators, (g) stand density, (h) egg deposition patterns, (i) phloem (food) thickness, and (j) stand structure. We constructed life tables which we analyzed using a competing risk analysis to determine the probability of death that could be attributed to specific mortality factors or a combination thereof. We are now attempting to develop a method of determining risk of infestation and loss due to mountain pine beetle within lodgepole pine stands.

ECOLOGICAL AND BIOLOGICAL RELATIONSHIPS

There are four general categories of knowledge that relate to the biological processes and ecological associations that exist within the mountain pine beetle *(Dendroctonus ponderosae* Hopk.)-lodgepole pine *(Pinus contorta* Dougl.) complex: (1) habitat types; (2) diameter classes; (3) phloem thickness; and (4) beetle populations.

Habitat Type

Habitat types are considered as reflections of differences in environments; both beetle and lodgepole pines react to a given environment in certain ways. Thus, beetle behavior and lodgepole pine survival rate will differ within different habitat types. Roe and Amman (1970) found this within the three major habitat types within which lodgepole pine grows in the Intermountain area: *Abies lasiocarpa/Vaccinium scoparium* (A/V) contained the least beetle activity--44 percent of the stands were actively infested; *Abies lasiocarpa/Pachistima myrsinites* (A/P) contained the most beetle activity--92 percent of the stands were actively infested; and within *Pseudotsuga menziesii/Calamagrostis rubescens* (P/C), 64 percent of the stands were actively infested. These habitat types generally relate to elevation within the lodgepole pine type of the Intermountain region; i.e., the A/V habitat type exists primarily at elevations above 8,500 feet, the A/P within the elevational zone of 6,500 to 8,500 feet, and the P/C habitat type grows below 6,500 feet. The relation of elevation to habitat type is important when considering the behavior of the beetle within these habitat types.

Amman (1969) found that brood production in bark of a given thickness is inversely related to elevation. Mountain pine beetle brood production is quite low, as is survival of the adult, above 8,000 feet--thus, the greater survival of lodgepole pine above this elevation. Up to 2 years may be required for the beetle to complete its life cycle at these higher elevations. Throughout the elevational zone sample, the survival of lodgepole pine was directly related to the elevation of the stand (Amman, in press). This was true even in the presence of an ample food supply (thick phloem and large diameters) at the higher elevations.

Tree Mortality Within Habitat Type

When a stand of lodgepole pine is attacked by the mountain pine beetle, obviously not all trees are killed. Beetles select the larger diameter trees each year, as well as over the life of an infestation (Cole and Amman 1969). In areas sampled, proportions of trees killed in various diameter classes ranged from 1.1 percent in the 4-inch diameter class to 87.5 percent in the 16-inch and greater class. Correlations between diameters of trees killed and year of kill were highly significant. Larger trees were selected by beetles in early years of the infestation; smaller trees were selected in later years. In these later years, both beetle and infested tree populations were decreasing.

Beetle infestation measured in the Intermountain region rose from approximately 0.5 to 5.0 trees per acre in the early years to a peak of 26 to 31 trees per acre; then declined to 2 to 3.5 trees per acre after most of the larger diameter trees had been killed. The intense period of infestation is usually rather short, lasting approximately 6 years. In our studies, overall tree *survival* has averaged 70 percent for trees 4 inches and greater in diameter.

Large trees produce not only more beetles per unit area of bark but also more per tree because of their greater surface area. Cahill (1960) observed that the height of infestation within a lodgepole pine tree was related to diameter at that height, not to diameter at breast height (d.b.h.). The figures for infestation height by Cahill and our figures on beetle emergence at d.b.h. were used to calculate the populations of beetles produced in trees of different sizes. These figures showed that beetle production could vary from 300 beetles for trees 8 to 9 inches d.b.h. to more than 15,000 for trees 18 inches d.b.h.

We found that 24 beetles per square foot at d.b.h. would be sufficient to infest and kill a tree using the assumption that the infestation rate was 12 female beetles per square foot of bark surface (the rate commonly observed in the field) and a 1:1 sex ratio. Thus, a tree 8 to 9 inches d.b.h. would produce only one-third enough beetles to infest and kill a 12-inch tree. Only infested trees 12 to 13 inches d.b.h. would produce more emerging than attacking beetles. If we assume that one-third to one-half of the beetles that emerge fail to make successful attacks (a conservative assumption), only trees 14 inches or larger d.b.h. would produce enough beetles to increase the infestation or maintain it at the previous year's level.

Relation of Beetle Emergence to Phloem Thickness

Insect population is apparently food-limited within a given area if only trees 14 inches and greater in d.b.h. produce enough beetles to maintain or increase the infestation and if, in fact, the beetle progressively destroys its preferred food supply. Generally speaking, the average thickness of phloem is greater in large than in small trees, and a greater proportion of the large trees is likely to have thick phloem.

Phloem thickness is one of the most important factors affecting mountain pine beetle survival. In our studies, phloem thickness was consistently and by far the strongest independent variable each year; it accounted for up to 62 percent of the variance in numbers of emerging beetles per square foot of bark surface. We found that the significant independent variables are phloem, stand density, and plot elevation for all but 1 percent of 66 percent total variation (Amman 1969).

BROOD SURVIVAL

Depth of phloem in small and large trees is the most obvious difference related to the survival of bark beetle broods. Larvae feed on phloem; thus, Amman (1969) hypothesized that the number of mountain pine beetles completing development withn a given area of bark depends on depth of phloem. Although the relation of phloem depth to tree diameter is highly variable, most trees having thick phloem are large in diameter; conversely, trees having thin phloem usually are small in diameter.

The effect of intraspecific competition within mountain pine beetle broods also is related to phloem (food supply) and population density. As the number of inches of egg gallery and, hence, the number of eggs per unit of bark increases, competition among the resulting larvae also increases. Consequently, survival of beetles decreases in a given area of bark, unless phloem depth (quantity) is sufficient to offset the effect of intraspecific competition.

Table 1.--*Probability and life expectation of a mountain pine beetle*

Stage	Pr_{ij}	$V(Pr_{ij})$	SE	$\hat{e}_i$	$V(\hat{e}_i)$	SE
Egg	0.776	0.00661	0.0813	114	168.03	12.96
E-2d instar	.222	.01001	.1000	113	134.36	11.59
E-2-4th instar	.197	.01692	.1301	57	69.29	8.33
E-2-4 pupae	.015	.01387	.1178	33	15.50	3.94
E-2-4-P adult	.010	.00769	.0877	15	6.76	2.60

Where the cause of death of an individual is not specific, the probability of an individual mountain pine beetle being alive at any one life stage and the life expectancy (in days) at that stage can be calculated using the competing risks analysis (Cole[1]). From our analysis of life tables, most of the events believed to cause critical change in the population occur in the third larval stage--crowding, food shortage, parasites, predators, and spring weather conditions. Such events coincide with the largest probability variation, which occurs in this third instar. The following example of brood survival (table 1) is based on three assumptions: (1) attack density is 12 females per square foot of bark; (2) each female beetle constructs 10 inches of egg gallery and oviposits 5.4 eggs per inch of this gallery; and (3) phloem depth is 0.10 inch. The total egg population for this situation would be 648.

PROJECTION OF CURRENT INFORMATION

The question now arises as to how this information can be combined and used to benefit the timber manager. Previously, most managers were immediately inclined to request chemical control action to halt an infestation of the mountain pine beetle in lodgepole pine. Amman and Baker (1972) compared lodgepole pine stand structures that sustained mountain pine beetle infestations. Some stands had been treated; others had not. Results showed that beetle populations declined in approximately the same number of years in both treated and untreated stands. Survival of lodgepole pine in these two types of stands was comparable with one exception; in two additional stands where the infestation was still active, chemical control had reduced the rate of tree mortality. In such situations, immediate logging of infested stands is recommended.

Roe and Amman (1970) have shown that the probability of infestation varies by habitat type. For example, there is about a 66 percent probability of lodgepole pine surviving to 16 inches d.b.h. in the *Abies lasiocarpa/Vaccinium scoparium* habitat type; but only about a 25 percent probability of surviving to this size in the *Abies lasiocarpa Pachistima myrsinites* (A/P) type. Cole and Amman (1969) have speculated that beetle population growth is food limited below 8,200 feet in elevation; above this elevation population growth is temperature (weather) limited.[2] These relationships coincide with habitat types within the lodgepole pine stands in the Intermountain region.

[1] Walter E. Cole. Mountain pine beetle dynamics in lodgepole pine forests: an approach and its analysis. Invitational paper given at IUFRO Congr., Gainesville, Fla., March 1971

[2] Gene D. Amman. The mountain pine beetle--dynamics and role in the lodgepole pine ecosystem. Invitational paper given at the Entomol. Soc. Am. Natl. Meet., Miami, Fla., December 1970.

It is now apparent that beetles select lodgepole pines of the largest diameter and those that usually have the thickest phloem; this upsets the persistent postulate that bark beetles select weakened, decadent trees. In lodgepole pines, trees containing the best growth and vigor (thickest phloem) offer the greatest potential for population buildup of beetles.

A simulation of beetle infestation in a lodgepole pine stand within an A/P habitat type has shown that the beetle can attack the larger diameter residual trees (at an approximate rate of 0.1 or less tree per acre) after an epidemic has run its course. The majority of the population emerging from these residual trees probably attacked the smaller diameter trees. Perhaps a few beetles may attack one or two larger diameter trees that can produce a surplus of beetles; this could sustain the beetle population period. Many relationships remain to be determined in the epidemiology of the mountain pine beetle. Furthermore, the simulated infestation showed that tree losses of epidemic magnitude can occur once the stand has enough trees to support an infestation.

Amman[3] has hypothesized that the relationship between associate insect populations and the mountain pine beetle is a primary factor in maintaining the latter population during long endemic periods; Amman is presently studying this relationship. The interdependence of governing factors at low population levels is without a doubt more involved than at a full scale epidemic.

This interaction of beetle with host tree relates to the ecosystem concept. Using this concept, we could project and predict the rise and fall of a mountain pine beetle empire and thus thoroughly evaluate the need for a decision by management. This means that we must possess intimate knowledge and the capability to detect, understand, and then quantify the governing (if not all) ecological processes acting within this dynamic association.

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[3]Gene D. Amman. Personal communication on file at Intermt. For. & Range Exp. Stn., USDA For. Serv., Ogden, Utah.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1973 — 784-293 / 7 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-171

July 1973

LODGEPOLE PINE LOSSES TO MOUNTAIN PINE BEETLE RELATED TO ELEVATION

Gene D. Amman, Bruce H. Baker, and Lawrence E. Stipe [1]

ABSTRACT

Mortality caused by the mountain pine beetle was related inversely to elevation and ranged from less than 1 to 17 percent of the lodgepole pine trees 4 inches d.b.h. and larger. Mortality of trees 9 inches d.b.h. and larger (those most often infested by mountain pine beetle), ranged from 2 percent of the stems or 0.8 percent of the basal area at the highest elevation to 36.5 percent of the stems or 36 percent of the basal area at the lowest elevation. Climate probably is the single most important factor accounting for variation in mortality of lodgepole pine at the different elevations because of its effect on the biology of the beetle.

The relation of lodgepole pine (*Pinus contorta* Dougl.) mortality caused by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) to various environmental factors is of importance in making control decisions. Control efforts might not be needed or might be deferred where risk of loss to the beetle is low. The relation of damage to habitat type (Roe and Amman 1970) on the Teton and Targhee National Forests is a step in this direction.

The principal objective of our study was to determine the relation of lodgepole pine mortality caused by the mountain pine beetle to elevation. The study was conducted on the North Slope of the Uinta Mountains in northern Utah and southern Wyoming where widespread infestation of the beetle occurred between 1956 and 1963 after which the infestation subsided.

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METHODS

Ten blocks consisting of approximately 4 square miles each were selected for sampling between Hoop Lake on the east to Mansfield Meadows on the west, a distance of approximately 20 airline miles. In this area, a major portion of the damage by the beetle occurred.

Twenty 1/10-acre plots were located in a grid pattern within each block. Patches of timber had to be sampled at low elevations because sagebrush predominated. Stands that were sampled were between 8,725 and 10,450 feet elevation because most lodgepole pine grows within this range of elevations on the North Slope of the Uinta Mountains.

All trees (both standing and on the ground) 4.0 inches diameter breast height (d.b.h.) and larger were recorded according to 1-inch d.b.h. classes (4.0-4.9, etc.). Similar records were made on other species of trees; however, these records were taken only from one-third of the plots sampled. If death was caused by the mountain pine beetle, such was noted. Phloem thickness was measured (in hundredths of inches) on opposite sides of each of two green lodgepole pine trees in each diameter class represented on each plot. The elevation of each plot also was recorded.

RESULTS AND DISCUSSION

Our sample data showed that lodgepole pine trees predominated at all elevations (table 1). Mortality of all lodgepole pine trees attributable to the mountain pine beetle ranged from less than 1 percent to 17 percent of the trees and was inversely related to elevation. At the lowest elevation, losses of trees 9 inches d.b.h. and larger were 36.5 percent of the stems or 36 percent of the basal area (fig. 1). At the highest elevation, these losses were 2 percent of the stems, or less than 1 percent of the basal area.

Although the regressions shown in figure 1 can be regarded as statistically significant, the scatter about the regression is large relative to the mean as indicated by $S_{y.x}$. Therefore, the curves should be used primarily for estimating gross relations to elevation and not specific responses for 1/10-acre plots within elevational levels.

The principal cause for variance in mortality of lodgepole pine among elevations probably is related to differences in climatic conditions that occur within the elevational strata; specifically, the effects of such differences on the biology and survival of the beetle. At high elevations on the Teton National Forest, cool temperatures delayed development so that a large proportion of the population entered the winter as eggs, and 1st and 2nd instars. In these stages, mortality was abnormally high under subfreezing conditions (Amman, in press).

Table 1.--*Stand composition (trees 4 inches d.b.h. and larger) by elevational levels at the start of the infestation*

Elevational level	Species and numbers and percent of trees per acre										Total
	Lodgepole pine		Douglas-fir		Engelmann spruce		Subalpine fir		Aspen		
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	
8,725-8,999	197	74	8	3	8	3	0	0	53	20	266
9,000-9,199	248	71	0	0	5	1	18	5	79	23	350
9,200-9,399	366	96	0	0	1	<1	10	3	4	1	381
9,400-9,599	293	100	0	0	0	0	0	0	0	0	293
9,600-9,799	311	88	0	0	25	7	18	5	0	0	354
9,800-9,999	308	83	0	0	34	9	30	8	0	0	372
10,000-10,400	320	88	0	0	30	8	15	4	0	0	365

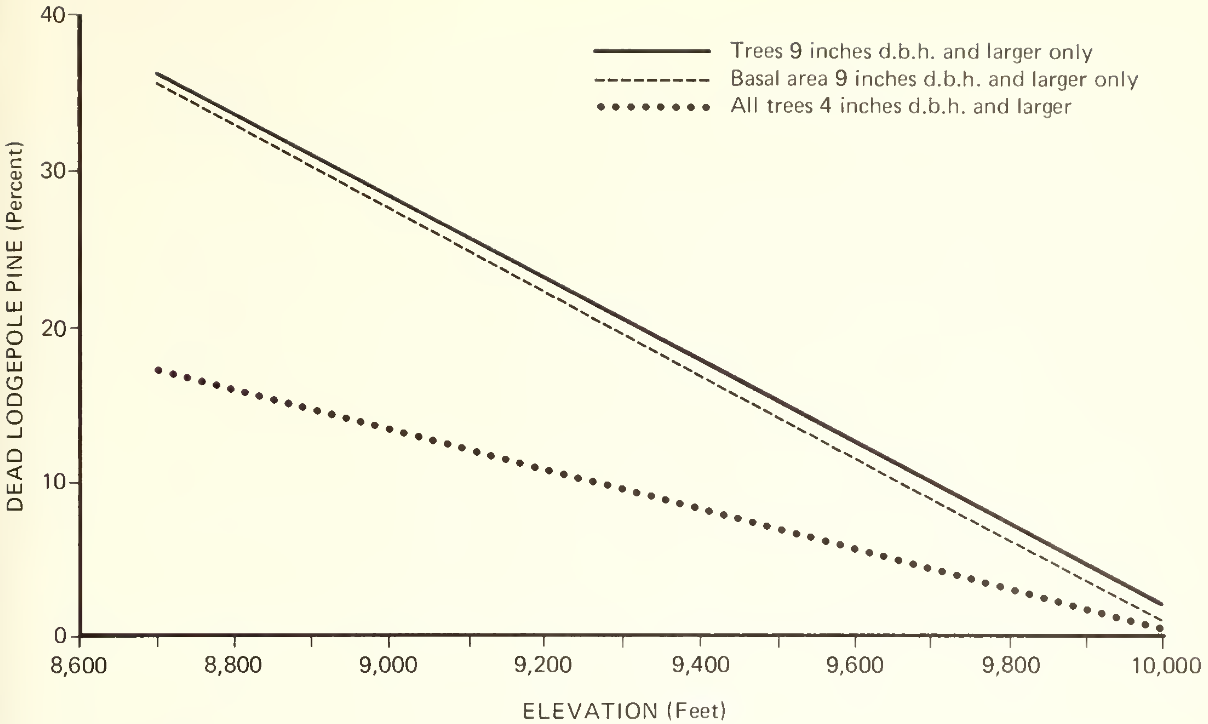

Figure 1.--Proportions of lodgepole pine stems and basal area killed by the mountain pine beetle in relation to elevation on the North Slope of the Uinta Mountains. (See Appendix for regression equations used to calculate these curves.)

Consequently, we compared data from this study with that obtained by Amman and Baker (1972) on the Teton National Forest in northwest Wyoming and adjacent Targhee National Forest in Idaho. In order to do this, we cast the Amman-Baker data according to elevational levels, and accounted for the difference in latitude by subtracting 700 feet from each North Slope elevation.

Hopkins' Bioclimatic Law called for a somewhat greater adjustment; however, factors other than elevation, latitude, and longitude enter into phenological comparisons between areas (Hopkins 1919).

The comparison in figure 2 shows a slight difference in the slopes of the regression lines; they crossed at about 8,500 feet. However, the differences in mortality for a given elevation when adjusted for latitude are minor; they range from about 3 percent at 8,000 feet to 4 percent at 9,000 feet (fig. 3). Therefore, most of the differences in mortality occurring at similar elevations can be accounted for by differences in latitude.

The number and proportion of large lodgepole pine trees per acre increased with elevation as shown in table 2. Therefore, stands at the higher elevations should have been more conducive to buildup of beetle populations than stands at the lower elevations because large infested trees usually produce more beetles per unit area of bark than do small trees (Reid 1963; Cole and Amman 1969). However, this did not occur, as reflected in figure 4.

Some feel that logging for railroad ties on the North Slope during the last century might have had some effect on the number of large trees growing at the time of the beetle infestation. Equally plausible, however, the stands could have reached a structure that would have been conducive to a beetle infestation before the 1950's without such cutting. If such had occurred, the mortality of trees probably would not have been any greater than our sampling showed.

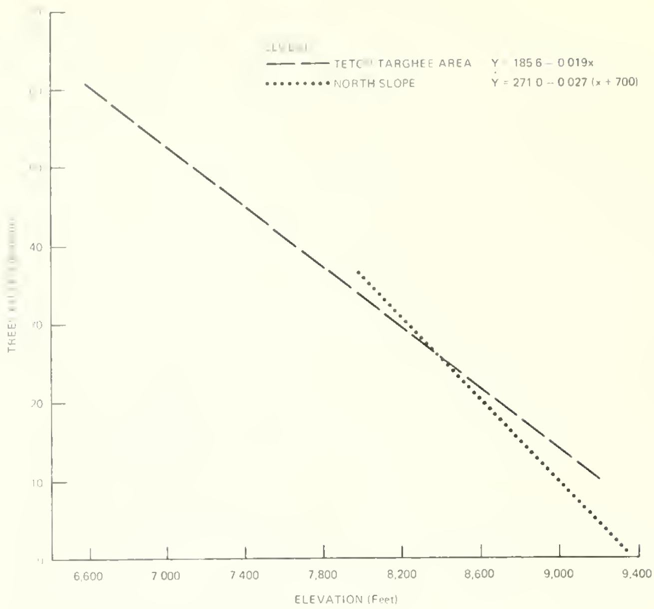

Figure 2.--Proportions of lodgepole pine stems 9 inches d.b.h. and larger killed by mountain pine beetles in relation to elevation on the Teton and Targhee National Forests and on the North Slope of the Uinta Mountains.

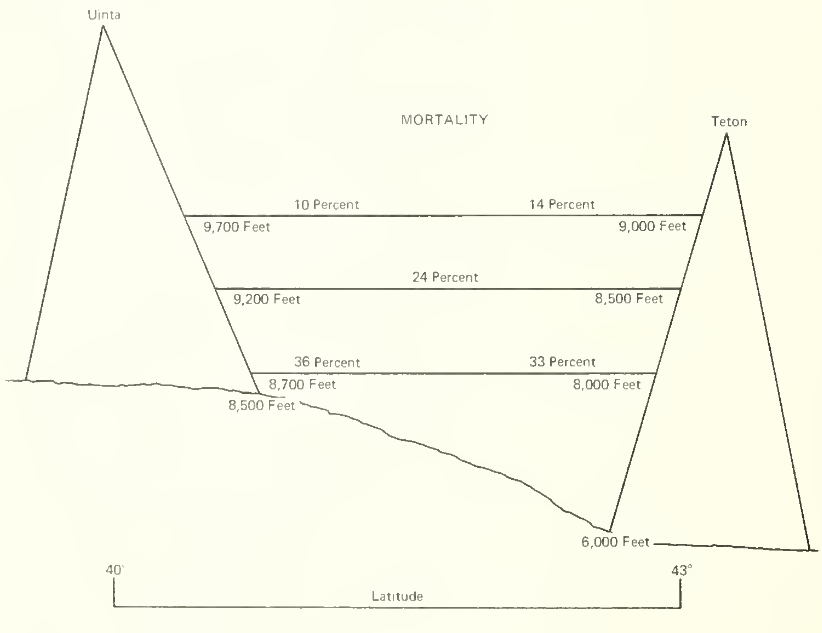

Figure 3.--Mortality of lodgepole pine in the Teton-Targhee area and North Slope of the Uinta Mountains attributable to the mountain pine beetle was approximately equal when elevation is corrected for differences in latitude.

Table 2.--*Numbers*[1] *per acre of lodgepole pine trees surviving (S), killed by the mountain pine beetle (MPB), and by other causes (OC) in seven elevation levels on the North Slope of the Uinta Mountains*

Tree size (d.b.h., inches)	8,725-8,999 (21)[2]			9,000-9,199 (39)			9,200-9,399 (29)			9,400-9,599 (32)			9,600-9,799 (40)			9,800-9,999 (25)			10,000-10,400 (14)		
	S	MPB	OC	S	MPB	OC	S	MPB	OC	S	MPB	OC	S	MPB	OC	S	MPB	OC	S	MPB	OC
4	40	0	1	47	[3]<1	3	81	0	6	42	0	3	45	0	1	58	0	2	33	0	0
5	31	1	4	44	1	3	68	0	7	47	<1	3	42	0	2	45	0	4	34	0	4
6	19	3	0	36	1	1	56	1	5	35	1	3	46	1	2	42	0	1	40	0	1
7	18	6	1	28	1	2	34	2	3	33	2	3	41	0	2	36	0	<1	39	0	1
8	16	6	<1	17	1	2	29	2	<1	33	4	3	36	2	1	31	<1	<1	36	0	1
9	12	7	1	13	3	<1	22	3	1	21	2	1	28	1	1	21	<1	0	24	0	3
10	6	4	<1	11	4	1	13	2	1	14	2	1	16	3	1	22	<1	<1	24	1	1
11	3	3	0	11	2	0	9	2	0	10	2	2	13	3	1	15	<1	0	21	0	1
12	7	1	0	7	2	0	6	3	0	8	3	0	8	2	1	9	0	0	18	0	0
13	2	2	0	2	2	0	2	1	1	4	1	0	5	1	1	5	0	0	11	0	0
14	<1	0	0	2	1	0	1	1	0	2	0	0	3	1	0	4	0	0	11	0	0
15	1	0	0	2	<1	0	2	1	0	2	<1	0	1	<1	0	5	0	0	9	0	1
16+	1	<1	0	1	1	0	1	2	0	5	2	0	3	2	<1	3	0	<1	8	0	0
Total trees/acre[4]	----197----			----248----			----366----			----293----			----311----			----308----			----320----		

[1]Numbers rounded to the nearest whole number except when less than one-half tree per acre.
[2]Number of 1/10-acre plots.
[3]<1 indicates less than one-half tree per acre.
[4]Number recorded on 1/10-acre plots, not summation of rounded numbers in this table.

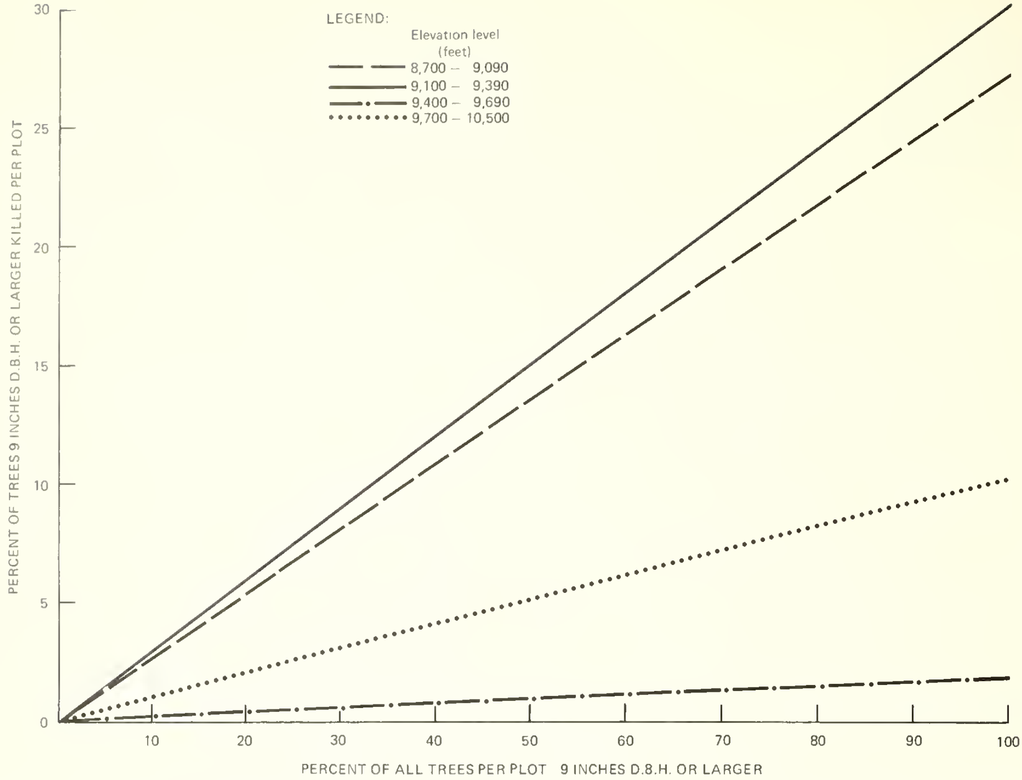

Figure 4.--Proportion of lodgepole pine trees 9 inches d.b.h. and larger killed by the mountain pine beetle in each 1/10-acre plot at different elevations in relation to the proportion of all lodgepole pine trees (4 inches d.b.h. or larger) that were 9 inches d.b.h. and larger in each 1/10-acre plot on the North Slope of the Uinta Mountains. (For regression equations, see Appendix.)

Average food conditions were about the same at all elevations. This was based on measurements made of phloem thickness, which is considered the principal factor regulating brood production of the mountain pine beetle in lodgepole pine forests where temperatures are optimum for development of the beetle (Amman 1969, 1972). The difference in average phloem thickness for trees 9 inches d.b.h. and larger was less than 0.01 inch (range of means 0.102 to 0.110 inch) (table 3). The small range in means probably can be attributed to ingrowth that occurred on residual trees at the lower elevations where mortality was greatest between the end of the infestation and the time we took our measurements. However, the potential for beetle infestation was much greater at the higher elevations because the number of phloem samples per acre equal to or exceeding 0.11 inch ranged between 30 at the lowest elevation to 113 at the highest elevation. Laboratory studies indicate that phloem thickness of 0.11 inch or greater could result in an increase in beetle populations (Amman 1972); therefore, it appears that the beetle was unable to utilize the food supply available at the higher elevations during the recent beetle infestation.

The effects of control treatments could not be evaluated. These included (a) chemical treatment (ethylene dibromide in diesel oil), (b) burning of individual standing trees, (c) logging, and (d) Operation Pushover, in which large blocks of trees were pulled over using a chain hooked between two crawler tractors and then burned. However, the close association of mortality with elevation indicates that a similar relation probably would have occurred if these control treatments had not been used. Furthermore, an evaluation of control based on stand structure in treated and untreated stands in the Teton and Targhee National Forests indicated that mortality was not reduced nor was the length of the infestation shortened (Amman and Baker 1972) as a result

Table 3.--*Number*[1] *and proportion of samples 0.11 inch or more thick per acre by diameter class, and average phloem thickness of all phloem samples for lodgepole pine 9 inches d.b.h. and larger*

Elevational level	Diameter class (inches) 9-10		11-12		13-14		15-16+		Total samples 0.11+	Phloem thickness all samples	
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	*No.*	*Percent*		*Mean*	*Standard deviation*
8,800	12	33	13	64	3	60	2	38	30	0.105	0.0030
9,000	18	37	15	42	5	57	5	83	43	.104	.0036
9,200	23	33	17	57	4	72	4	64	48	.104	.0033
9,400	17	25	20	55	6	53	9	61	52	.103	.0036
9,600	44	50	20	48	7	46	2	20	73	.106	.0034
9,800	35	41	23	47	10	54	10	61	78	.110	.0039
10,000	37	39	39	50	17	38	20	59	113	.105	.0041

[1] Two samples were taken per tree.

of those treatments. In stands where treatment slowed the rate of tree mortality in the Teton-Targhee area, the infestation was prolonged; however, the ultimate amount of mortality was approximately the same both in treated and untreated stands.

As a result of Operation Pushover, a small portion of the North Slope is now covered by blocks of different-age stands of lodgepole pine, replacing what had been a large even-age forest. The North Slope possibly would be least susceptible to widespread beetle infestations in the future if more of these different-age stands could be created over a larger portion of the Slope. Obviously, it would be much easier to combat infestations in scattered stands than it would be within an extensive forest because individual stands can be logged quickly.

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APPENDIX

The following regression equations, which are based on individual observations from 1/10-acre plots were used to calculate the curves shown in figure 1:

(1) Stems 4 inches d.b.h. and larger--$\hat{Y} = 129.8 - 0.0129\ X$; $\bar{Y} = 7{\cdot}7$; $S_{y \cdot x} = 14$; $r^2 = 0.11$; $N = 200$; $P < 0.005$.

(2) Stems 9 inches d.b.h. and larger--$\hat{Y} = 268 - 0.0266\ X$; $\bar{Y} = 16.4$; $S_{y \cdot x} = 26.9$; $r^2 = 0.13$; $N = 193$; $P < 0.005$.

(3) Basal area of stems 9 inches d.b.h. and larger--$\hat{Y} = 275.5 - 0.0275\ X$; $\bar{Y} = 16$ ($S_{y \cdot x}$ and r^2 not meaningful because the regression is on means).

Regression equations used to calculate curves shown in figure 4:

(1) 8,700-9,090 feet; $\hat{Y} = 0.0815 + 0.2704\ X$; $\bar{Y} = 0.18$; $S_{y \cdot x} = 0.21$; $r^2 = 0.10$; $P < 0.10$.

(2) 9,100-9,390 feet; $\hat{Y} = -0.0112 + 0.3015\ X$; $\bar{Y} = 0.08$; $S_{y \cdot x} = 0.13$; $r^2 = 0.27$; $P < 0.005$.

(3) Regressions for the two highest elevations were not significantly different from zero.

U.S. GOVERNMENT PRINTING OFFICE: 1973

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
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OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-172

July 1973

ENERGY REQUIRED TO DRY WOOD

David P. Lowery[1]

ABSTRACT

Ponderosa pine and Douglas-fir test specimens were dried by means of two drying schedules. The total electrical energy data, watt-hours required to dry the specimens to either 15 or 30 percent moisture content, were analyzed statistically. Models, based on all study data for each species, were also developed.

The wood drying process can be divided into three major stages: (1) warmup period; (2) the constant rate period; and (3) the falling rate period. In the warmup period, energy is required to heat the drying environment and the material; consequently, the rate of moisture loss from the wood surfaces is relatively slow. In the constant rate period, the energy requirement is fairly uniform as moisture moves through the wood (primarily by capillary action). Moisture is lost at a constant rate. The rate itself depends on the ability of the circulating air to remove water from the wood surfaces. In the falling rate period, the energy requirement increases considerably. Energy is required to rupture the bond between water and cellulose or lignin molecules as well as to diffuse moisture vapor to the surface. In this period, the rate of drying decreases with a decrease in the amount of moisture.

In most wood drying operations, the total energy used exceeds that required to dry wood at the optimum rate. Because energy consumed is one of the direct costs of drying wood, information concerning this factor is needed if the drying process is to be evaluated. The following study was made to evaluate the energy requirements of two different drying regimes--(1) in which the surface temperature was maintained at a relatively constant level; and (2) in which the oven temperature was held constant throughout the drying period. It was believed that less energy would be required by the surface temperature regime because of its more direct control over the drying process.

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[1]Wood Technologist in Missoula, Montana, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Montana.

PROCEDURE

Two ponderosa pine and two Douglas-fir boards were used in this study. The newly sawn, select boards, 1 by 8 inches by 16 feet, were obtained at local Missoula sawmills. Boards were cut into test specimens, 20 inches long. The specimens, identified as to board and position within board, were stored under water to prevent drying until needed.

Specimens were dried in accordance with one of two drying regimes. In the first regime, the oven was set at 138° C. (280° F.) and maintained at this level throughout the drying period. In the second regime, surface temperature of the specimen was held at 90° C. (194° F.) by decreasing the oven temperature until consecutive oven temperature readings (taken 15 minutes apart) were the same. At this time, the surface temperature of the test specimen was slightly less than the oven temperature. The oven was then returned to its original setting of 138° C. and maintained at this setting for the remainder of the drying period. For all specimens, the oven was started after the specimen had been positioned inside. The initial temperature setting was 138° C.

During the drying period, specimen weight, surface temperature, and oven temperature were recorded at 15-minute intervals. In addition, chart records were obtained of the electrical consumption (watt-hours) and the surface temperature. At the completion of the drying period, the specimen was placed in a second oven and dried to a constant weight. This constant (ovendry) weight was used to calculate the specimen's specific gravity (green volume) and the initial and intermediate percent moisture contents.

Four specimens, selected at random from each board, were dried in accordance with each of the two drying regimes; thus eight ponderosa pine and eight Douglas-fir specimens were dried at constant oven temperature and the same number of each species were dried at constant surface temperature.

RESULTS AND DISCUSSION

Data obtained from the test specimens are summarized in table 1. The mean specific gravity of ponderosa pine board 1 specimens was 0.441 and the range 0.028; the average initial percent moisure content was 149 and the range 23 percent. For ponderosa pine board 2 specimens, the average specific gravity was 0.503 and the range 0.091; the average initial moisture content percent was 115 and the range 41 percent. For the Douglas-fir test specimens obtained from board 1, the average specific gravity was 0.408 and the range 0.059; the average initial percent moisture content of these specimens was 88 and the range 42 percent. For board 2, the average specific gravity was 0.403 and the range 0.077; the average initial percent moisture content was 109 and the range 74 percent.

Contrary to expectation, ponderosa pine boards had a higher specific gravity than Douglas-fir boards. However, the average initial percent moisture content was usually greater for ponderosa pine specimens than for the Douglas-fir specimens, as was expected.

Other data shown in the table are the average times, in minutes, needed to dry the specimens to average moisture contents of 30 and 15 percent, and the average watt-hours required to attain these moisture contents. As would be expected, the average times and the average watt-hours required to dry to 15 percent moisture content were greater than were needed to dry to 30 percent moisture content. A comparison of the drying regimes shows that the constant surface temperature schedule usually required longer average times and greater average watt-hours.

Table 1.--*Summary of the data for all test specimens*[1]

Board no.	Drying schedule[2]	Average specific gravity	Average initial moisture content	Average time to dry to 30% MC	Average watt-hours to dry to 30% MC	Average time to dry to 15% MC	Average watt-hours to dry to 15% MC
			Percent	*Minutes*		*Minutes*	
				PONDEROSA PINE			
1	COT	0.442	146	172	16,555	225	20,345
	CST	.439	153	188	15,771	266	19,805
2	COT	.507	109	172	16,699	248	21,829
	CST	.499	122	229	17,379	311	22,615
				DOUGLAS-FIR			
1	COT	.409	79	120	12,165	199	17,061
	CST	.406	98	254	14,822	270	19,561
2	COT	.395	105	169	15,899	244	21,516
	CST	.411	113	225	16,880	308	22,771

[1]Each value in the table is the average of four test specimens.

[2]The drying schedules used were constant dry bulb or oven temperature (COT) and constant surface temperature (CST).

The total watt-hours of electrical energy required to dry the individual test specimens to moisture contents of 30 and 15 percent was subjected to analysis of variance. None of the controlled study variables were significant.

Since no differences were detected between drying regimes, a model was developed using all the data for each species to show the relationship between watt-hours of energy required to dry to 15 percent moisture content, initial percent moisture content, and specific gravity. The Douglas-fir model (fig. 1) had the following equation:

Watt-hours to 15 percent moisture content

$$= \left[A - \left\{\frac{A - 4}{(145)^N}\right\} (160 - IM)^N\right] 1011.854$$

where:

$A = 59.091\ (SG) + 1.736$

$N = 4.0909\ (SG)$

IM = Initial percent moisture content

SG = Specific gravity

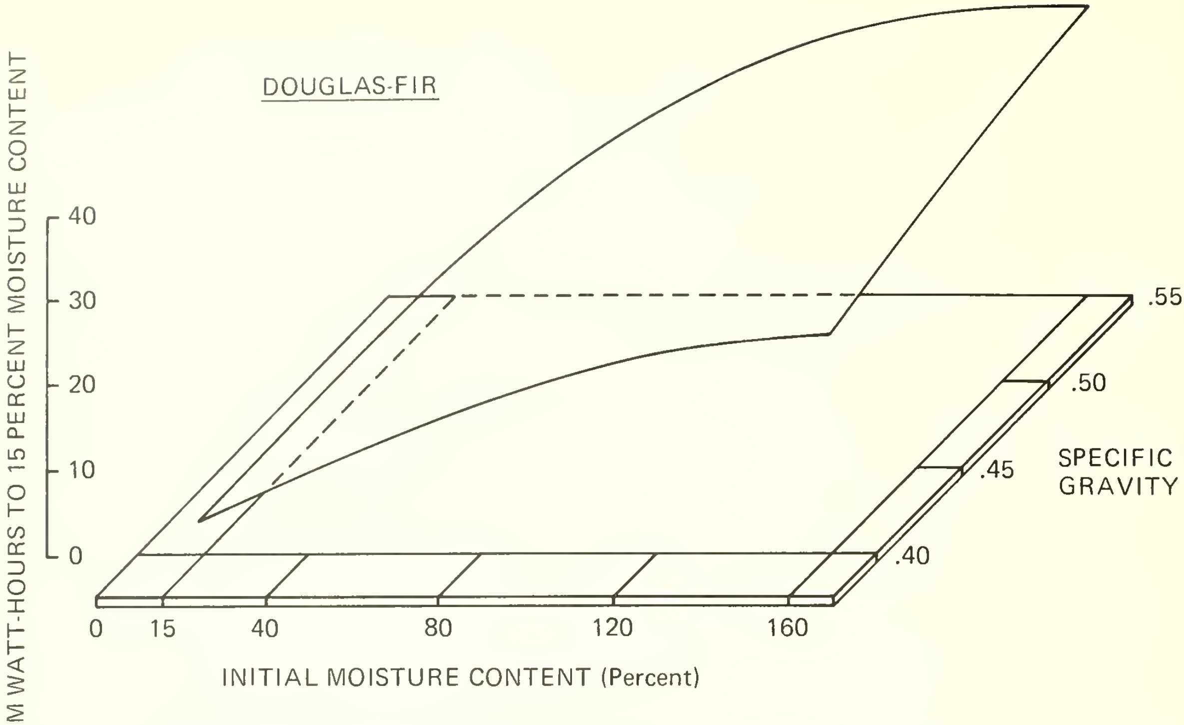

Figure 1.--Douglas-fir model showing relationship between watt-hours required to dry to 15 percent moisture content, initial percent moisture content, and specific gravity; R^2 = 0.80; standard error of estimate 1,200; mean watt-hours was equal to 20,227, based on 16 test specimens.

The model limits were: specific gravity 0.35-0.50 and initial percent moisture content, 60-160. The equation, based on 16 specimens, has an R^2 of 0.80 and a standard error of estimate of 1,200 watt-hours.

The model shows that the specific gravity and initial percent moisture content variables were positive as expected, and an increase in either value increased the watt hour requirement.

The ponderosa pine model (fig. 2) has the following equation:

Watt-hours to 15 percent moisture content

$$= \left[A - \left\{\frac{A - 4}{(145)^N}\right\} \quad (160\text{-}IM)^N\right] 977.062$$

where:

A = 100 (SG) - 22.7

N = 3.0645 (SG) - 0.291

IM = Initial percent moisture content

SG = Specific gravity

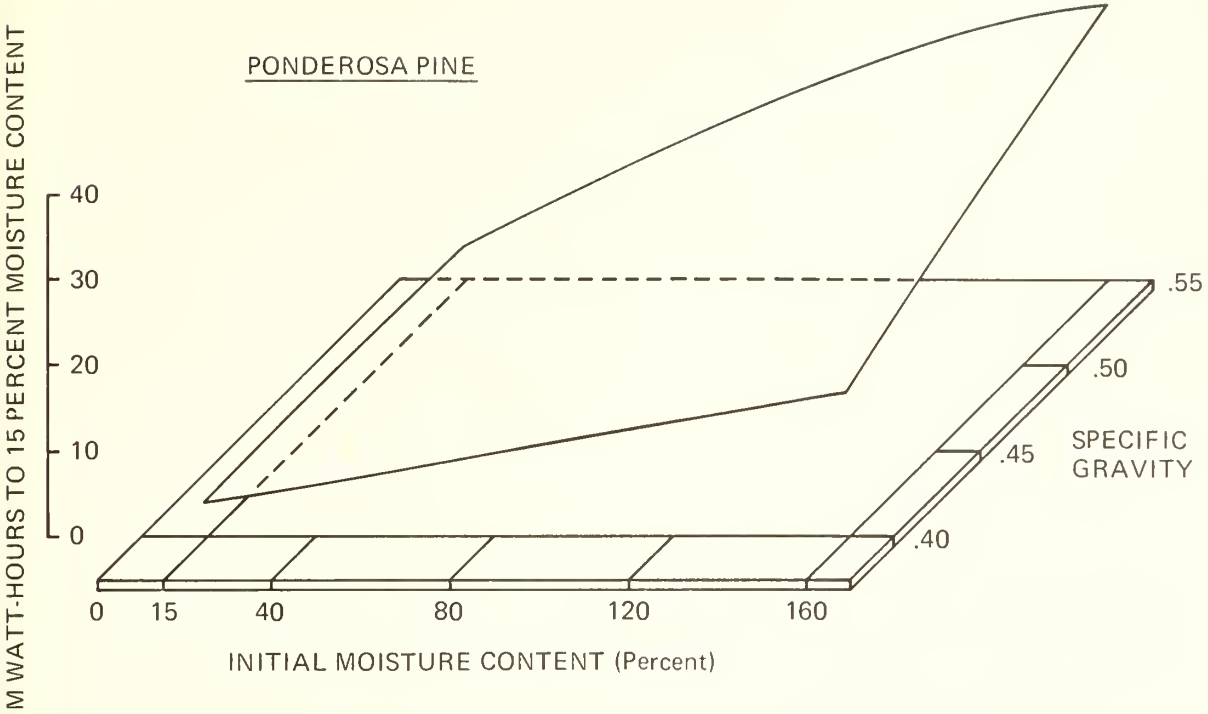

Figure 2.--Ponderosa pine model showing relationship between watt-hours to dry to 15 percent moisture content, initial percent moisture content, and specific gravity; $R^2 = 0.20$; standard error of estimate 2,100; mean watt-hours was equal to 21,148, based on 15 specimens.

The data limits for the model were: specific gravity, 0.40-0.55, and initial moisture content, 90-160 percent. The equation, based on 15 specimens, has an R^2 of 0.20 and a standard error of estimate of 2,100.

One reason for the weakness of the ponderosa pine model is the somewhat narrower range in the initial moisture content of the test specimens. The average range was 32 percent; that for the Douglas-fir was 58 percent.

CONCLUSIONS

Results of this study indicated no significant difference between constant surface temperature and constant oven temperature regimes in the total electrical energy (watt-hours) required to dry wood specimens to a given moisture content. This is contrary to expectation in that the test specimens were subjected to different drying regimes and were of different species, specific gravity, and initial percent moisture content.

Models, based on the study data, show that the effects of specific gravity and initial percent moisture content were positive and interactive; so an increase in either variable increased the watt-hour requirement.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

JSDA Forest Service
Research Note INT-173

August 1973

A COMPUTER SUBROUTINE FOR CALCULATING LOG VOLUMES BY THE INTERNATIONAL RULE

J. E. Brickell[1]

ABSTRACT

Describes a FORTRAN computer subroutine for calculating board foot volume of sawlogs according to the International rule, assuming either 1/8-inch or 1/4-inch saw kerf.

Any association with the furtherance of use of the board foot as a unit of volume ıeasurement should weigh heavily on the conscience of a responsible forest mensuration- st. All the same, on the grounds that if one is going to use a bad procedure he should o it in a way that minimizes the undesirable effects, this Note presents a computer ubroutine to calculate *accurately* the board foot volume of any reasonably sized log ccording to the assumptions of the International rule. The standard taper rate can e modified if the user desires.

The International log rule (Clark)[2] is a formula rule. Unlike some of the other ormula rules, the International rule generates a discrete set of equations that ontains a different equation for each log length. By contrast, the Doyle rule and imilar rules that give inferior results are expressed by one formula in which log ength is a variable. For example, the International rule (1/8-inch kerf) calculates oard foot volume of a 4-foot stem segment as

$$V_4 = 0.22\, D_s^2 - 0.71\, D_s \qquad (1)$$

here

D_s = scaling diameter of the piece in inches

[1]Mensurationist stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, hich is maintained in cooperation with the University of Idaho.

[2]J. F. Clark. Measurement of sawlogs. For. Quart. 4:79-93. 1906.

As a result, assuming one-half inch of taper per 4 feet of log length, the board foot volume of an 8-foot log is

$$\begin{aligned} V_8 &= 0.22\ D_s^2 \qquad\qquad - 0.71\ D_s \\ &+ 0.22\ (D_s + 0.5)^2 - 0.71\ (D_s + 0.5) \\ &= 0.44\ D_s^2 - 1.2\ D_s - 0.3 \end{aligned} \tag{2}$$

For a 12-foot log, board foot volume is

$$\begin{aligned} V_{12} &= 0.22\ D_s^2 \qquad\qquad - 0.71\ D_s \\ &+ 0.22\ (D_s + 0.5)^2 - 0.71\ (D_s + 0.5) \\ &+ 0.22\ (D_s + 1.0)^2 - 0.71\ (D_s + 1.0) \\ &= 0.66\ D_s^2 - 1.47\ D_s - 0.79 \end{aligned} \tag{3}$$

By adding still another 4-foot segment, Bruce and Schumacher[3] show the derivation of the volume formula for 16-foot logs. Obviously, one can derive formulae for 20-foot logs, 24-foot logs, and so on *ad absurdum*.

In general, the International 1/8-inch formula is

$$V = 0.22 \sum_{i=1}^{n} [D_s + t(i-1)]^2 - 0.71 \sum_{i=1}^{n} [D_s + t(i-1)] \tag{4}$$

where

D_s = the log's scaling diameter

n = the number of 4-foot sections in the log

t = taper (one-half inch per 4 feet is the standard International rule assumption)

By careful use of the inequality symbols in determining n, equation (4) can be considered a continuous function of log length. However, equation (4) is not continuously differentiable; that is, it is not a "smooth curve." Therefore, it is difficult to express the International rule as a single equation using scaling diameter and log length for use in a computer program. Nevertheless, some people have attained reasonable success by writing the coefficients of equations (1), (2), (3), and others, as functions of log length (Stage and others[4]). The coefficient of D_s^2 is linear with respect to length, and the coefficient of D_s has only one critical point, but the constant term in the equation requires at least cubic powers of log length for close approximation over an extended range of log lengths. This creates a risk of bad predictions (inherent in the use of polynomials) when extrapolating even a little way beyond the range of points to which the approximating equation was fitted.

---

[3]Donald Bruce and Francis X. Schumacher. Forest Mensuration. McGraw-Hill Book Co., Inc., New York. 483 p., illus. 1950.

[4]Albert R. Stage, Richard C. Dodge, and James E. Brickell. NETVSL--a computer program for calculation of tree volumes with interior defect. U.S. For. Serv., Res. Pap. INT-51. 30 p., illus. 1968.

To avoid such risk, equation (4) has been programed in a computer subroutine which embodies the following procedures, all of which conform to the National Forest Log Scaling Handbook (FSH 2409.11):

1. If the log is less than 1 foot longer than an integer multiple of 4 feet, volume in the excess length is discarded at the small end of the log. Scaling diameter is moved toward the butt a distance equal to the excess length and increased by a small amount; this amount is equal to the product of taper rate and excess length. In short, trim allowance is taken off the small end of the log.

2. If the log is 1 or more but less than 4 feet longer than an integer multiple of 4 feet, volume in the portion of the additional length that is an integer number of feet is scaled and the rest discarded. The segment is scaled at the top end of the log after excess length has been discarded, and the remainder of the log is scaled in 4-foot segments.

3. The subroutine's default taper rate is one-half inch per 4 feet of log length. However, if diameter at a log's large end is measured and passed to subroutine JCLARK (see fig. 1), an average taper rate for the log will be determined and used to calculate board foot volume. One would expect that this default option probably would be used most often in order to conform to standard practice, but for logs having little or excessive taper the other option is available.

The variables in the calling sequence for JCLARK are as follows:

DS = diameter inside bark at the log's small end (scaling diameter).

DL = $\begin{cases} \text{0.0 if the default taper option (one-half inch) is to be used.} \\ \text{d.i.b. at the log's large end otherwise.} \end{cases}$

TL = total log length, including trim allowance.

KERF = $\begin{cases} \text{1 if 1/4-inch saw kerf is assumed.} \\ \text{0 if 1/8-inch saw kerf is assumed.} \end{cases}$

V = board foot volume returned to the calling program.

Log volumes computed using this subroutine are the same as those given in tables X and XI of the National Forest Log Scaling Handbook. In these tables, however, logs not having a length that is an integer multiple of 4 feet are assigned a volume by linear interpolation. JCLARK actually computes the volume of such logs. For an 18-foot log that has a scaling diameter of 120 inches, the difference between tabulated volume and calculated volume is 0.051 board foot. This is less than trivial except in those cases where rounding to the nearest 10 board feet might proceed in a different direction because of this slight difference. The program will not compute volumes for logs less than 4 feet long. Most log rules, including the International, were never intended for logs of extremely small diameter. Chipping headrigs were not widely used in 1906; thus, a user may get a negative answer if he attempts to calculate the board feet of 1 by 2 that can be produced from a 2.4-inch log.

JCLARK has been tested on an IBM 360/67, but it should operate on almost any system having a FORTRAN compiler available.

```
      SUBROUTINE JCLARK (DS,DL,TL,KERF,V)
C     *-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*
C     THIS SUBROUTINE WAS WRITTEN BY J.E.BRICKELL OF THE U.S.FOREST SERVICE
C     TO CALCULATE BOARD FOOT VOLUME OF SAWLOGS BY THE INTERNATIONAL RULE.
C     VARIABLES IN THE CALLING SEQUENCE ARE:
C           DS    = LOG'S SCALING DIAMETER (INCHES)
C           DL    = DIB AT LOG'S LARGE END (INCHES) (0.0 IF 1/2 INCH TAPER)
C           TL    = TOTAL LOG LENGTH (FEET)
C           KERF >0 IF KERF ASSUMPTION IS 1/4 INCH
C           KERF <0, OR = 0, IF KERF ASSUMPTION IS 1/8 INCH
C           V     = LOG VOLUME RETURNED TO THE CALLING PROGRAM
C     *-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*-*
      V=0.0
C     IF TOTAL LOG LENGTH IS LESS THAN FOUR FEET NO BOARD FOOT VOLUME WILL
C     BE COMPUTED.
      IF(TL-4.0)10,1,1
C     IF THE LOG'S LARGE END DIAMETER IS FURNISHED TO JCLARK A TAPER RATE
C     WILL BE COMPUTED.  IF DL=0 THE STANDARD ASSUMPTION OF 1/2 INCH PER 4
C     FEET OF LOG LENGTH WILL BE USED.
    1 IF(DL)3,3,2
    2 T=4.0*(DL-DS)/TL
      GO TO 4
    3 T=0.5
C     THE FOLLOWING LOOP (THROUGH STATEMENT 5) FINDS OUT HOW MANY FULL 4
C     FOOT SEGMENTS THE LOG CONTAINS.
    4 DO 5 I=1,20
      IF(TL-FLOAT(4*I))6,5,5
    5 CONTINUE
    6 L=I-1
      SL=FLOAT(4*L)
C     THE FOLLOWING STATEMENT MOVES THE SCALING DIAMETER DOWN TO THE END OF
C     THE 4 FOOT SEGMENTS AND INCREASES IT ACCORDING TO TAPER.
      D=DS+(T/4.0)*(TL-SL)
C     THE FOLLOWING LOOP (THROUGH STATEMENT 7) FINDS OUT HOW MANY FULL FEET
C     OF LENGTH ARE IN THE SEGMENT LESS THAN 4 FEET LONG.
      DO 7 I=1,4
      XI=FLOAT(I)
      IF(SL-TL+XI)7,7,8
    7 CONTINUE
C     THE NEXT THREE STATEMENTS CALCULATE VOLUME IN THE 1, 2, OR 3 FOOT
C     SEGMENT AT THE SMALL END OF THE LOG.
    8 XL=XI-1.0
      DEX=DS+(T/4.0)*(TL-SL-XL)
      VADD=0.055*XL*DEX*DEX-0.1775*XL*DEX
C     THE FOLLOWING LOOP (THROUGH 9) CALCULATES VOLUME IN THE PORTION OF
C     THE LOG CONTAINING WHOLE 4 FOOT SEGMENTS.
      DO 9 I=1,L
      DC=D+T*FLOAT(I-1)
    9 V=V+0.22*DC*DC-0.71*DC
      V=V+VADD
C     IF 'KERF' IS GREATER THAN ZERO, INTERNATIONAL 1/8 INCH VOLUME AS
C     COMPUTED ABOVE WILL BE CONVERTED TO INTERNATIONAL 1/4 INCH VOLUME.
      IF (KERF)10,10,11
   10 RETURN
   11 V=0.905*V
      RETURN
      END
```

Figure 1.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
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OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-174

September 1973

SPACE MANAGEMENT AT FIRE-WEATHER STATIONS

William C. Fischer[1]

ABSTRACT

This paper provides criteria for proper use of instrument shelters and suggests installation of additional special purpose shelters for other than temperature-recording instruments.

A well-equipped fire station can provide a wide range of reliable weather data both for fire-weather forecasting and for fire-danger rating purposes. Unfortunately, this capability can be compromised by poor space management. Too often, the instruments listed, such as the wind counter, and the wind direction indicator, are installed in the weather station's lone instrument shelter (fig. 1).

Figure 1.--This situation is not nearly as exaggerated as you might think.

[1]Research forester, stationed at Northern Forest Fire Laboratory, Missoula, Mont.

PURPOSE OF INSTRUMENT SHELTER

The instrument shelter (more properly termed the thermometer shelter or thermoscreen) was specifically designed to minimize radiant heat effects while allowing free movement of outside air past the temperature-sensitive instruments inside. Therefore, use of the instrument shelter to house a variety of instruments that are not temperature sensitive, in addition to the maximum-minimum thermometer, psychrometer, and hygrothermograph, can seriously interfere with the shelter's primary function; the free flow of air through the shelter is restricted and a source of radiant heat supplied inside the shelter. Temperature errors resulting from such interference are especially likely during periods of light wind.

SCALE SHELTERS

The answer to the space problem at fire-weather stations is relatively simple. Part of the solution was supplied by Barney[2] when he designed the Appalachian scale shelter. This shelter is an ideal installation for the measurement of fuel moisture sticks (fig. 2). Many stations are equipped with triple beam balances instead of Appalachian scales. In this event, a scale shelter similar to the one shown in figure 3 is appropriate.

Figure 2.--Appalachian scale shelter in use at fire-weather station.

[2]Richard J. Barney. Appalachian scale shelter. USDA For. Serv. Intermt. For. & Range Exp. Stn. Res. Note 88, 7 p., illus., 1962.

Figure 3.--A shelter built to house a triple beam balance.

Some fire-weather station managers may be reluctant to build scale shelters at this time because of the trend toward development of an inorganic fuel moisture analog for fire-danger rating. Such a device would replace fuel moisture sticks and hopefully eliminate the need for scales and scale shelters. The inorganic fuel moisture analog is *at least* 2 or 3 years away. Moreover, the final version of the new analog may have to be weighed--much in the same manner as fuel moisture sticks are weighed at present. Besides, what may happen 2 or 3 years from now is not a good excuse for collecting unreliable weather data this year. If a weather station is worth having, every effort should be made to insure the accuracy and comparability of the data collected.

ACCESSORY SHELTER

The remainder of the space problem can be eliminated by construction and use of an accessory shelter similar to that shown in figure 4. This shelter is actually a modification of the Appalachian scale shelter. It is designed to house a mechanical wind counter, a wind direction indicator, and a variety of tools and supplies, such as batteries, hygrothermograph ink and charts, psychrometer wicking, a supply of distilled water, brushes for cleaning instruments, etc. Even if the wind counter and wind direction indicator are located in a nearby office, the accessory shelter can still provide a handy all-purpose storage area at the weather station.

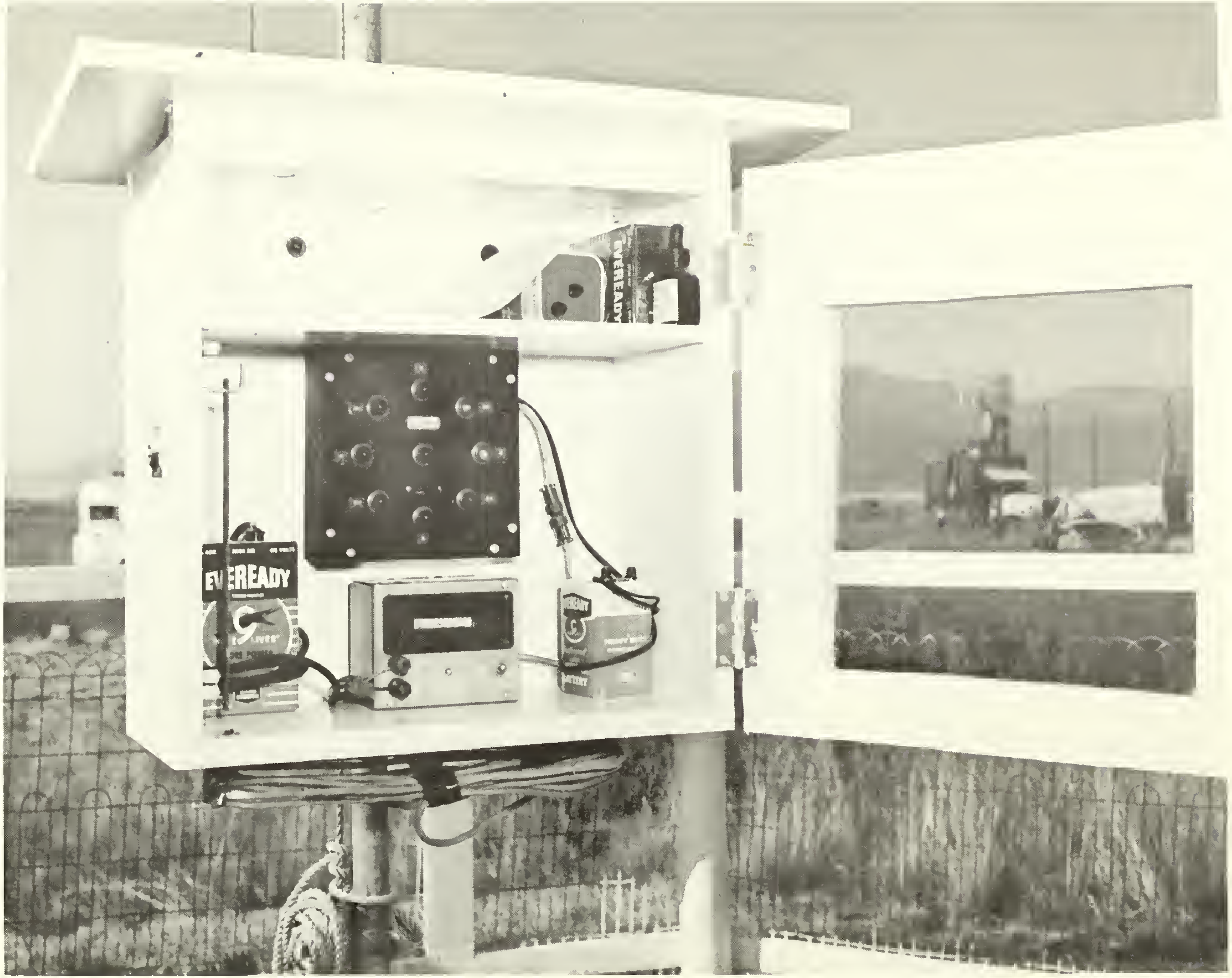

Figure 4.--Accessory shelter mounted on anemometer pole.

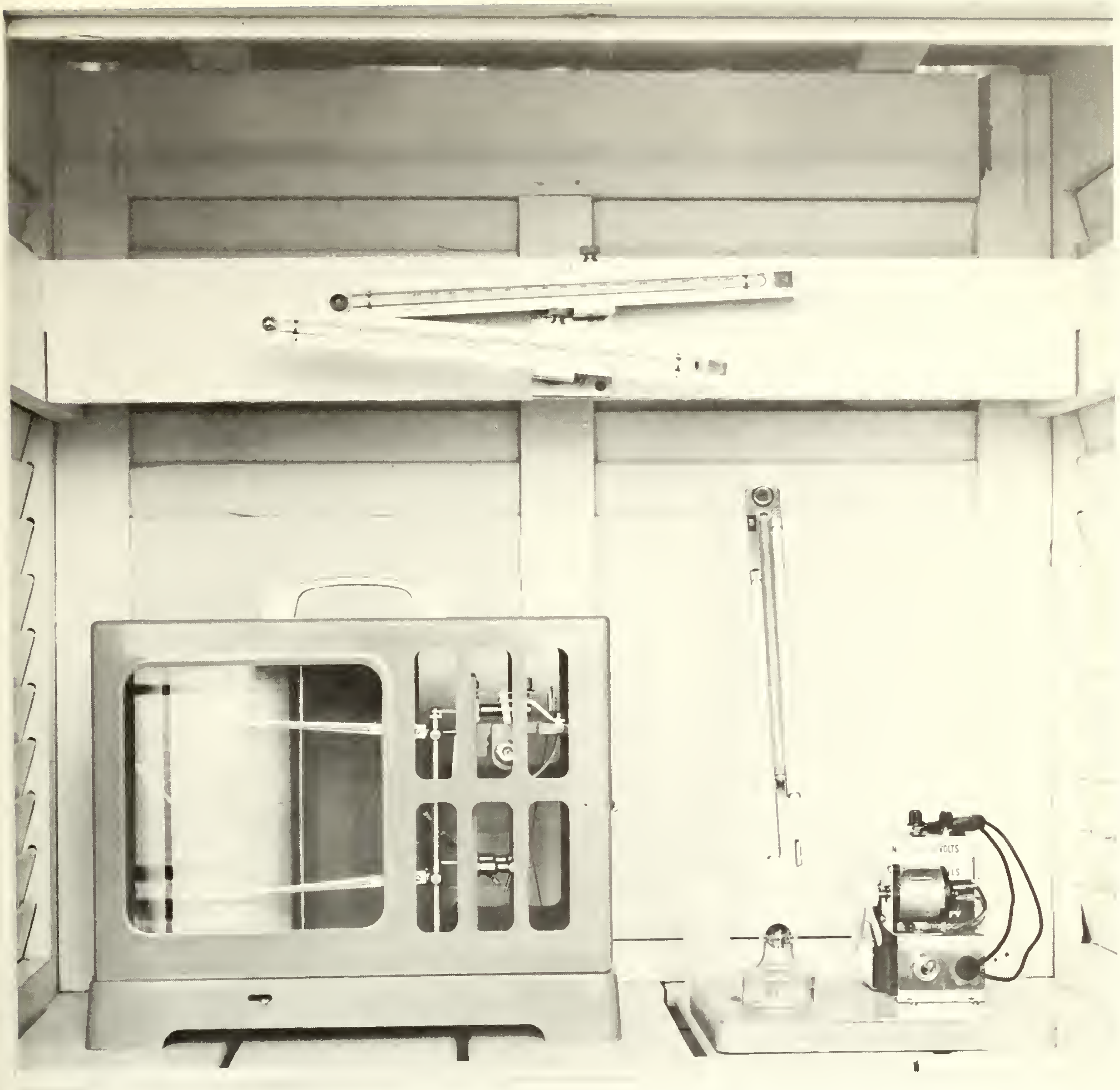

Figure 5.--Proper use of instrument shelter.

Construction details and installation instructions for both the Appalachian scale shelter and the accessory shelter are contained in the recently published "Fire-Weather Observers' Handbook."[3]

Use of these or similar type shelters at a fire-weather station will provide sufficient space for reading instruments that are not heat sensitive. The instrument shelter can then be used solely for the measurement of air temperature (fig. 5).

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[3]William C. Fischer and Charles E. Hardy. Fire-weather observers' handbook. USDA For. Serv., Intermt. For. & Range Exp. Stn., 152 p., illus., 1972.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research NOTE INT-175

September 1973

GROUND COVER ALTERNATIVES AT FIRE-WEATHER STATIONS

William C. Fischer[1]

ABSTRACT

Results indicate that either a bed of gravel or of coniferous needles would provide an acceptable substitute in areas where natural vegetation is lacking and cannot be maintained without irrigation.

Instrument shelters at fire-weather stations should be situated over a low, well-clipped cover of natural vegetation because the instrument shelters are used to obtain temperature readings that are representative of the surrounding outside air. To minimize radiant heat effects on the instruments inside, the shelter should be painted white, inside and out, and provided with a double roof. Sides should be louvered to allow free movement of air past the instruments without allowing entry of radiant heat. Openings in the shelter floor also contribute to air movement inside the shelter.

The type of ground surface under the instrument shelter is important for much the same reasons. A smooth, light-colored surface, such as concrete, can reflect the sun's rays directly into the shelter through openings in the sides and floor. A dark surface, such as blacktop, quickly absorbs great amounts of the sun's heat. This causes the air above such a surface to become warmer than the surrounding air. Unless carried off by wind, this warm air can rise and enter the shelter through side and floor openings. A natural vegetation ground cover usually minimizes excessive heating by convection and by reflection.

WHAT IF VEGETATION WON'T GROW?

If your fire-weather station needs to be located in an area where vegetation won't grow--on bare, rocky mountaintops or in excessively dry valley bottoms--ground surfaces of gravel and forest litter have been suggested as alternatives to natural vegetation in such situations. A third alternative, bare ground, is not generally considered acceptable because it can become dusty during dry periods and muddy during wet periods.

[1]Research Forester, stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

FOUR GROUND COVERS STUDIED

A study was conducted at the Ant Flat Work Center in northwestern Montana's Kootenai National Forest to find out what differences in instrument shelter temperature would occur over different ground surfaces. A grassy flat was divided into four adjoining plots measuring 25 feet on each side. At the center of each plot, a standard Weather Service type instrument shelter was installed. A different ground surface was established under each shelter (fig. 1): (1) a low-clipped natural vegetation; (2) a 2-inch-deep duff bed of coniferous needles; (3) a 2-inch-deep bed of washed medium-sized gravel; and (4) a low-clipped watered lawn. Each shelter was equipped with a set of standard maximum-minimum thermometers and an electric fan psychrometer.

On the watered lawn plot, a small rotary sprinkler was operated every other morning from 8 to 9 a.m. Water was not applied if 0.10 inch or more precipitation occurred during the previous 24-hour period. The watered lawn plot was located downwind to prevent the other plots from being affected by moisture.

Daily observations of dry bulb, wet bulb, maximum, minimum, and current temperatures[2] were taken from each of the four instrument shelters during July, August, and September of 1967 and 1968. To minimize differences resulting from various observation times, readings were taken between 5 and 6 p.m., when temperatures usually held steady in the study area. All readings were completed in 10 minutes. Instruments were rotated between shelters each week to minimize instrument bias.

The 65 sets of observations obtained in this experiment were analyzed for statistically significant differences. Using the t test for paired plots, daily readings taken over each of the three alternative surfaces were compared in turn to the readings

Figure 1.--Three of the four study plots are seen here; the conifer needle litter plot is out of sight. The observer is at the natural vegetation plot, the gravel plot in the lower right, and the watered lawn in the upper right.

[2]Current temperature read from minimum thermometer.

taken over the natural vegetation surface. The windspeed at observation time, which averaged 3.2 mi/h for all observations, was not considered during initial data analysis. However, the effect of windspeed was taken into consideration for subsequent analysis.

HOW THEY COMPARED

Initial analysis found statistically significant differences (95 percent confidence level) between current and maximum temperatures taken over the watered lawn and similar measurements taken over the standard natural vegetation surface (table 1). The figures in table 1 are averages; therefore, they do not reflect the range of variation that occurred between individual readings for the same day. However, they do indicate the conditions sampled and the direction of the differences. It is reasonable to assume that differences shown for the watered lawn plot would have been larger had a more liberal irrigation schedule (one more closely approximating actual practice) been followed.

Subsequent analyses, which considered windspeed at observation time, verified these initial findings and pointed out several additional differences. In comparing observations recorded for the watered lawn with those for the natural vegetation, statistically significant differences appeared between current temperature readings whenever windspeeds averaged less than 5 mi/h. On the other hand, minimum temperature differed significantly when windspeed was less than 2 mi/h or more than 5 mi/h, but not when windspeed ranged between 3 to 5 mi/h. A significant difference in wet bulb temperature under light wind conditions (0 to 2 mi/h) was also indicated.

The only other additional statistically significant differences occurred during periods of calm or light winds (0 to 2 mi/h). These differences involved current temperature over the gravel surface and wet bulb temperature over the bed of coniferous needle litter.

APPLICATION

The general requirement that weather station instrument shelters be established over a ground surface of natural vegetation is sound. Besides being a relatively neutral reflective surface, the cover remains basically unaltered by rain and wind and is easy to maintain in a uniform low-clipped condition. Because uniformity of observation practice is a major factor in quality control, alternative ground covers should be considered only where vegetation is lacking and its establishment and maintenance impossible without artificial watering.

This study supports the general prejudice against irrigating in the vicinity of a fire-weather station. It also indicates that a coniferous needle bed or a bed of washed gravel can provide acceptable alternative ground surfaces for fire-weather station instrument shelters if a vegetative cover cannot be established and maintained without irrigation.

If a bed of gravel or litter is used under the instrument shelter, any differences in temperature readings from what might be expected over a standard natural vegetation surface are likely to occur only during periods of low windspeeds or calm. Since daily observation time usually is set to sample the most severe fire-danger conditions (i.e., when windspeed and temperature are near their daily peaks and relative humidity near its daily low), such differences should not occur often enough to be a serious problem.

DOES NOT APPLY TO FUEL STICKS

These results should only be applied to temperature and humidity measurements obtained inside a standard Weather Service type shelter installed 4 feet above the ground surface. *Do not* apply these results to the exposure of fuel moisture sticks or other analogs of fuel moisture. These devices are commonly located just above the ground surface and could be greatly affected by ground cover characteristics.

Table 1.--*Averages of all measurements taken over the four different ground surface treatments*[1].

Ground surface treatment	Average temperatures										Average relative humidity	
	Max. temp.		Min. temp.		Current temp.		Wet bulk temp.		Dry bulb temp.			
	Average	Diff.	Average	Diff.	Average	Diff.	Average	Diff.	Average	Diff.	Average	Diff.
	°F.										Percent	
Natural vegetation	81.0		39.5		76.5		56.4		76.3		34.0	
Conifer needle litter	80.9	-0.1	39.3	-0.2	76.5	0	56.3	-0.1	76.3	0	33.5	-0.5
Gravel	80.9	-.1	39.5	0	76.3	-.2	56.4	0	76.2	-.1	34.1	+.1
Watered lawn	80.7	[2]-.3	39.6	+.1	76.2	[2]-.3	56.4	0	76.1	-.2	34.5	+.5

[1] Differences in windspeed are not considered in this summary.

[2] Statistically significant difference (95 percent confidence level).

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
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OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-176

October 1973

FOREST AREA AND TIMBER VOLUME FOR HARDING, BUTTE, AND MEADE[1] COUNTIES, SOUTH DAKOTA, 1971

Shirley H. Waters and Gary W. Clendenen[2]

ABSTRACT

Presents classification of total land area by Forest Survey standards as well as timber volume data according to species, forest type, stand-size class, and ownership.

OXFORD: 524.61:524.3. KEYWORDS: forest surveys (regional), stand volume, forest area classification

Data presented in this Note are based on a comprehensive timber survey made in western South Dakota during 1971 by the South Dakota State Forestry Department in cooperation with the USDA Forest Service Rocky Mountain Region and the Intermountain Forest and Range Experiment Station.

LAND AREA

Approximately 3 percent of the total land area (3,712,000 acres) in Harding, Butte, and Meade[1] Counties, South Dakota (fig. 1) is forested. This area was classified according to Forest Survey land classes as shown in the following tabulation:[3]

Land class	*M acres*
Commercial forest land regulated	80.9
Commercial forest land unregulated	1.8
Unproductive forest land	21.4
Productive reserved forest land	0
Total forest land	104.1
Nonforest land	3,608.3
Total land area	3,712.4

[1]Includes the portion of Meade County that is west of the 103rd meridian.
[2]Respectively, Programer and Assistant Resource Analyst, Forest Survey, Ogden, Utah 84401. Mr. Clendenen is presently Range Conservationist, USDA Forest Service, Intermountain Region, Big Piney Ranger Station, Big Piney, Wyoming 83113.
[3]See "Terminology" on page 8 for definitions of Forest Survey terms.

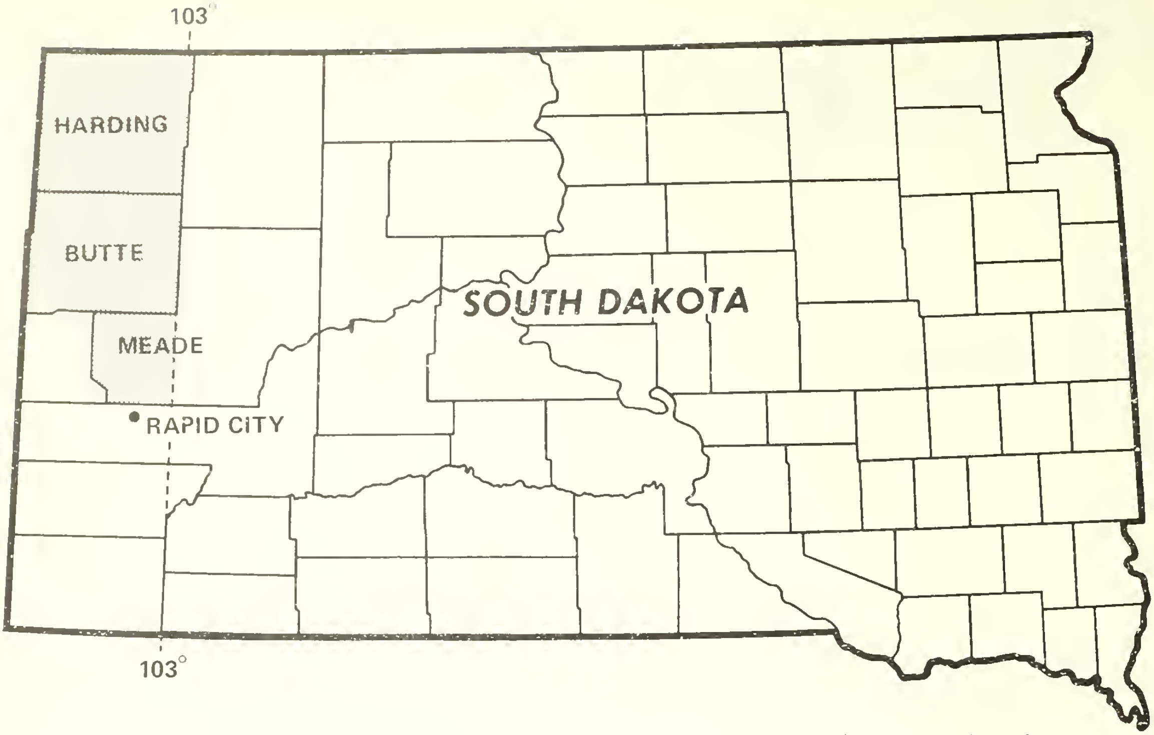

Figure 1.--Location of Harding, Butte, and Meade Counties, South Dakota.

SPECIES

On the 81,000 acres of commercial forest land, trees containing almost 56 million cubic feet (157 million board feet) were growing, of which 96 percent was ponderosa pine, *Pinus ponderosa,* as shown in the following tabulation:

Species	*Growing stock (M ft^3)*	*Sawtimber (Mfbm)*
Softwoods:		
Ponderosa pine	53,576	149,439
White spruce (*Picea glauca*)	173	545
Other	7	[4]0
Total	53,756	149,984
Hardwoods:		
Aspen (*Populus tremuloides*)	26	0
Cottonwood (*Populus sp.*)	1,048	5,373
Other	1,129	2,067
Total	2,203	7,440
Total	55,959	157,424

[4]Not sufficient acreage to be represented in the sample.

STAND SIZE

Sawtimber and poletimber stands cover about 76,000 acres (table 1), which represents 94 percent of the commercial forest land and accounts for 99 percent (55 million cubic feet) of the growing stock volume, as reflected in the following tabulation:

Stand-size class	*Growing stock ($M\ ft^3$)*	*Sawtimber (Mfbm)*
Sawtimber stands	34,655	124,824
Poletimber stands	20,594	31,092
Seedling/sapling stands	672	1,343
Nonstocked area	38	165
Total	55,959	157,424

Table 1.--*Area of commercial forest land by stand-size class and forest type for Harding, Butte, and Meade*[1] *Counties, South Dakota, 1971*

Stand-size class	Softwoods		Hardwoods		Total
	Ponderosa pine	White spruce	Aspen	Other	
	M acres				
Sawtimber	36.2	--	--	4.6	40.8
Poletimber	33.7	--	--	1.7	35.4
Seedling/sapling stands	4.1	--	--	--	4.1
Nonstocked areas	.6	--	--	--	.6
Total	74.6	--	--	6.3	80.9

[1]Only that portion of Meade County west of the 103rd meridian is reported in this table.

Table 2.--*Area of commercial forest land by ownership class and forest type for Harding, Butte, and Meade*[1] *Counties, South Dakota, 1971*

Ownership class	Softwoods: Ponderosa pine	Softwoods: White spruce	Hardwoods: Aspen	Hardwoods: Other	Total
	M acres				
Public:					
National Forest	42.8	--	--	--	42.8
Other federal	1.1	--	--	0.2	1.3
Total	43.9	--	--	.2	44.1
State, county, and municipal	4.2	--	--	.8	5.0
Total	48.1	--	--	1.0	49.1
Private:					
Farm	15.2	--	--	3.1	18.3
Miscellaneous private[2]	11.3	--	--	2.2	13.5
Total	26.5	--	--	5.3	31.8
Total	74.6	--	--	6.3	80.9

[1]Only that portion of Meade County west of the 103rd meridian is reported in this table.
[2]Includes land owned by forest industries.

Table 3.--*Area of commercial forest land by ownership class and stand-size class for Harding, Butte, and Meade*[1] *Counties, South Dakota, 1971*

Ownership class	Stand-size class: Sawtimber	Poletimber	Seedling/ sapling	Nonstocked	Total
	M acres				
Public:					
National Forest	18.7	19.4	4.1	0.6	42.8
Other federal	.7	.6	--	--	1.3
Total	19.4	20.0	4.1	.6	44.1
State, county, and municipal	2.9	2.1	--	--	5.0
Total	22.3	22.1	4.1	.6	49.1
Private:					
Farm	11.5	6.8	--	--	18.3
Miscellaneous Private[2]	7.0	6.5	--	--	13.5
Total	18.5	13.3	--	--	31.8
Total	40.8	35.4	4.1	.6	80.9

[1]Only that portion of Meade County west of the 103rd meridian is reported in this table.
[2]Includes land owned by forest industries.

OWNERSHIP

Almost 61 percent of the commercial forest land in Harding, Butte, and Meade Counties is publicly owned--the Black Hills National Forest in Meade County and the Custer National Forest in Harding County (table 2). Sawtimber and poletimber stands grow about equally on public lands, but there are more sawtimber stands than there are poletimber stands on private lands (table 3). The volume of growing stock is slightly more on public lands than it is on private lands, as shown in the following tabulation:

Ownership class	*Growing stock ($M\ ft^3$)*	*Sawtimber (Mfbm)*
Public:		
National Forest	25,558	71,585
Other federal	1,045	2,770
Total	26,603	74,355
State, county, and municipal	3,543	9,374
Total	30,146	83,729
Private:		
Farm	15,063	45,073
Miscellaneous private[5]	10,750	28,622
Total	25,813	73,695
Total	55,959	157,424

[5]Includes land owned by forest industries.

NONCOMMERCIAL FOREST LAND

Farmers own almost 62 percent of the 21,000 acres of noncommercial forest land in these three counties. Hardwoods (mostly oak) grow on 66 percent of these noncommercial forest lands, ponderosa pine on 23 percent, and other softwoods on the remaining 11 percent. The ponderosa pine is not capable of producing crops of industrial wood because of adverse site conditions (table 4).

Table 4.--*Area of noncommercial forest land by ownership class and forest type for Harding, Butte, and Meade[1] Counties, South Dakota, 1971*

Ownership class	Softwoods			Hardwoods		Total
	Ponderosa pine	White spruce	Other	Aspen	Other	
	M acres					
Public:						
National Forest	2.1	--	--	--	--	2.1
Other federal	[2]NS	--	--	--	0.4	.4
Total	2.1	--	--	--	.4	2.5
State, county, and municipal	.5	--	0.3	--	.9	1.7
Total	2.6	--	.3	--	1.3	4.2
Private:						
Farm	1.7	--	1.6	--	9.9	13.2
Miscellaneous private[3]	.7	--	.5	--	2.8	4.0
Total	2.4	--	2.1	--	12.7	17.2
Total	5.0	--	2.4	--	14.0	21.4

[1]Only that portion of Meade County west of the 103rd meridian is reported in this table.

[2]Not significant; less than 0.05 M acres.

[3]Includes land owned by forest industries.

DATA RELIABILITY

Total land area for Harding, Butte, and Meade Counties was determined by a 100 percent map census and, therefore, has no sampling error.

Sampling error estimates were not available for the National Forest data presented, so the national accuracy standards prescribed in the Forest Service Handbook (4813.1, 11.1--1) were assumed: 3 percent per million acres on commercial forest land area, 10 percent per million acres on noncommercial forest land area, and 10 percent per billion cubic feet for volume. The Black Hills National Forest and the Custer National Forest are not entirely included within the three counties; consequently, the sampling errors associated with the National Forest estimates may be either greater or less than the national accuracy standards.

On non-National Forest lands, forest land area and timber volume were estimated from a double sample using aerial photos for the area estimates and ground plots for the volume estimates. Sampling error estimates are 2.0 percent per million acres for commercial forest land area; 1.8 percent per million acres for noncommercial forest land area; 2.1 percent per billion cubic feet for total cubic-foot volume; and 4.8 percent per billion board feet for total board-foot volume.

TERMINOLOGY

Forest type.--Forested land classified according to plurality species of living trees.

FOREST SURVEY LAND CLASSES:

Commercial forest land.--Forest land that is producing or is capable of producing crops of industrial wood (20 cubic feet per acre per year).

Commercial forest land regulated.--Commercial forest land that is included in the allowable cut timber base.

Commercial forest land unregulated.--Commercial forest land that is not included in the allowable cut timber base because the timber occurs in isolated patches and stringers, unstable soils, and so forth.

Unproductive forest land.--Forest land that is not capable of producing crops of industrial wood (20 cubic feet per acre per year) because of adverse site conditions.

Productive reserved forest land.--Commercial forest land that has been withdrawn from timber production through statute or administrative regulation.

Nonforest land.--Land that does not support a forest cover.

STAND-SIZE CLASSES:

Sawtimber stands.--Stands at least 10 percent stocked with growing stock trees having a minimum net volume of 1,500 board feet (International ¼-inch rule) in sawtimber trees (9.0 inches diameter at breast height (dbh) and larger for softwoods and 11.0 inches dbh and larger for hardwoods).

Poletimber stands.--Stands failing to meet the sawtimber criteria, but at least 10 percent stocked with poletimber and larger trees (5.0 inches dbh and larger) and at least the minimum stocking in poletimber size trees.

Seedling/sapling stands.--Stands failing to meet both the sawtimber and poletimber criteria, but having at least 10 percent stocking in trees of commercial species and with at least half the stocking in seedling and sapling size trees (less than 5.0 inches dbh).

Nonstocked areas.--A forest land area not qualifying for any of the above stand-size classes; i.e., usually an area of less than 10 percent stocking.

TREE SIZE CLASSES:

Growing stock trees.--All noncull trees 5.0 inches dbh and larger.

Sawtimber trees.--Softwood trees 9.0 inches dbh and larger and hardwood trees 11.0 inches dbh and larger.

VOLUMES:

Growing stock volume.--Net cubic-foot volume of all live merchantable trees 5.0 inches dbh and larger from a 1-foot stump to a minimum 4.0-inch top diameter outside bark.

Sawtimber volume.--Net International ¼-inch rule board-foot volume of live merchantable sawtimber trees.

U.S. GOVERNMENT PRINTING OFFICE: 1973 — 784-486 / 22 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-177

October 1973

FOREST AREA AND TIMBER VOLUME FOR LAWRENCE COUNTY, SOUTH DAKOTA, 1971

Gary W. Clendenen and Shirley H. Waters[1]

ABSTRACT

Presents classification of total land area by Forest Survey standards as well as timber volume data according to species, forest type, stand-size class, and ownership.

OXFORD: 524.61:524.3. KEYWORDS: forest surveys (regional) stand volume, forest area classification

Data presented in this Note are based on a comprehensive timber survey made in western South Dakota during 1971 by the South Dakota State Forestry Department in cooperation with the USDA Forest Service Rocky Mountain Region and the Intermountain Forest and Range Experiment Station.

LAND AREA

Approximately 70 percent of the total land area (512,000 acres) in Lawrence County, South Dakota (fig. 1) is forested. This area was classified according to Forest Survey land classes as shown in the following tabulation:[2]

Land class	*M acres*
Commercial forest land regulated	338.1
Commercial forest land unregulated	.7
Unproductive forest land	17.9
Productive reserved forest land	0
Total forest land	356.7
Nonforest land	155.3
Total land area	512.0

[1]Respectively, Assistant Resource Analyst and Programer, Forest Survey, Ogden, Utah 84401. Mr. Clendenen is presently Range Conservationist, USDA Forest Service, Intermountain Region, Big Piney Ranger Station, Big Piney, Wyoming 83113.

[2]See "Terminology" on page 8 for definitions of Forest Survey terms.

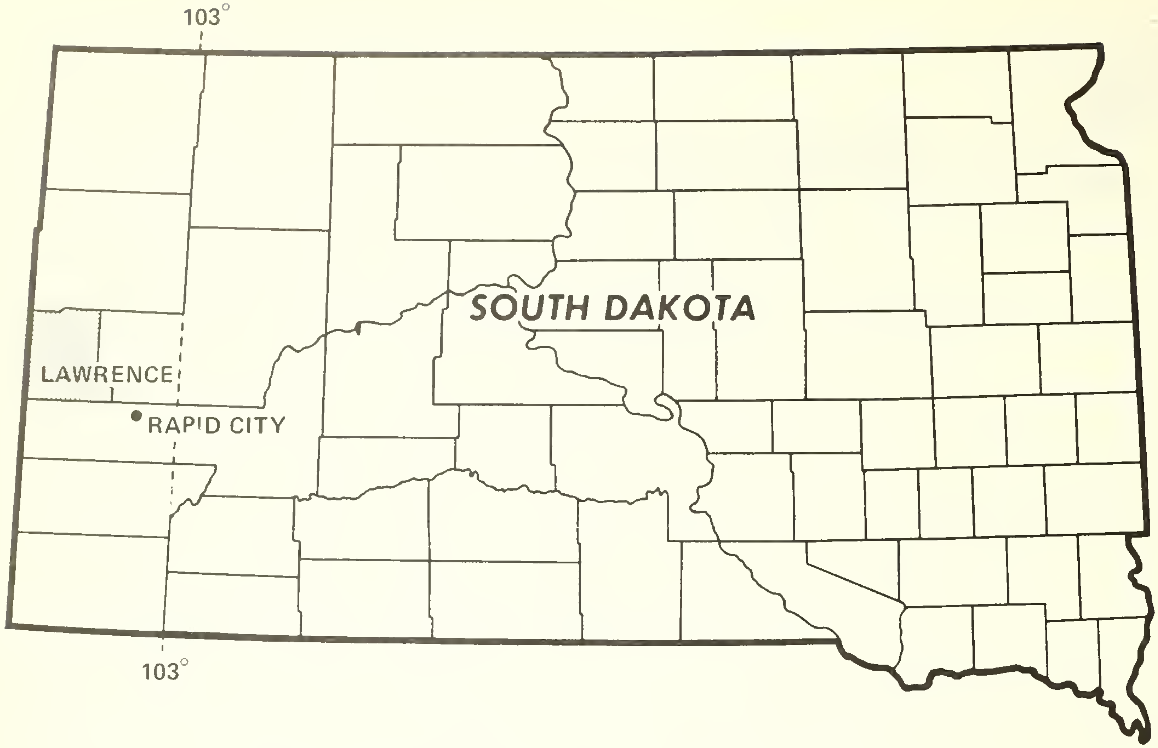

Figure 1.--Location of Lawrence County, South Dakota.

SPECIES

On the 338,000 acres of commercial forest land, trees containing almost 356 million cubic feet (1.3 billion board feet) were growing, of which 87 percent were ponderosa pine (*Pinus ponderosa*), as shown in the following tabulation:

Species	*Growing stock* (*M ft*^{3})	*Sawtimber* (*Mfbm*)
Softwoods:		
Ponderosa pine	310,666	1,129,571
White spruce (*Picea glauca*)	40,600	168,643
Total	351,266	1,298,214
Hardwoods:		
Aspen (*Populus tremuloides*)	2,504	631
Other	1,888	1,747
Total	4,392	2,378
Total	355,658	1,300,592

STAND SIZE

Sawtimber stands cover about 245,000 acres (table 1), which represents 72 percent of the commercial forest land and accounts for 85 percent (303 million cubic feet) of the growing stock volume, as reflected in the following tabulation:

Stand-size class	*Growing stock ($M\ ft^3$)*	*Sawtimber (Mfbm)*
Sawtimber stands	303,226	1,213,885
Poletimber stands	51,329	82,376
Seedling/sapling stands	599	2,177
Nonstocked area	504	2,154
Total	355,658	1,300,592

Table 1.--*Area of commercial forest land by stand-size class and forest type for Lawrence County, South Dakota, 1971*

Stand-size class	Softwoods: Ponderosa pine	Softwoods: White spruce	Hardwoods: Aspen	Hardwoods: Other	Total
	- - - - - -	- - - - - -	*M acres*	- - - - - -	- - - - - -
Sawtimber	208.1	17.1	1.2	18.2	244.6
Poletimber	73.5	1.5	--	3.0	78.0
Seedling/sapling stands	8.7	[1]NS	--	--	8.7
Nonstocked areas	6.8	--	--	--	6.8
Total	297.1	18.6	1.2	21.2	338.1

[1]Not significant; less than 0.05 M acres.

OWNERSHIP

More than 80 percent of the commercial forest land in Lawrence County is publicly owned. The typical acre is a ponderosa pine sawtimber stand on the Black Hills National Forest (tables 2 and 3). Obviously, the majority of the growing stock and sawtimber tree volume is also located on this National Forest, as shown in the following tabulation:

Ownership class	*Growing stock (M ft^3)*	*Sawtimber (Mfbm)*
Public:		
National Forest	244,554	907,850
Other federal	7,662	25,848
Total federal	252,216	933,698
State, county, and municipal	6,525	23,284
Total	258,741	956,982
Private:		
Farm	53,451	192,797
Miscellaneous private[3]	43,466	150,813
Total	96,917	343,610
Total	355,658	1,300,592

[3] Includes land owned by forest industries.

Table 2.--*Area of commercial forest land by ownership class and forest type for Lawrence County, South Dakota, 1971*

Ownership class	Softwoods: Ponderosa pine	Softwoods: White spruce	Hardwoods: Aspen	Hardwoods: Other	Total
	- - - - - -	- - - - - -	M acres	- - - - - -	- - - - - -
Public:					
National Forest	249.3	13.3	--	--	262.6
Other federal	3.6	.4	[1]NS	1.1	5.1
Total	252.9	13.7	NS	1.1	267.7
State, county, and municipal	2.7	.3	NS	1.4	4.4
Total	255.6	14.0	NS	2.5	272.1
Private:					
Farm	22.2	2.4	.7	11.4	36.7
Miscellaneous private[2]	19.3	2.2	.5	7.3	29.3
Total	41.5	4.6	1.2	18.7	66.0
Total	297.1	18.6	1.2	21.2	338.1

[1]Not significant; less than 0.05 M acres.
[2]Includes land owned by forest industries.

Table 3.--*Area of commercial forest land by ownership class and stand-size class for Lawrence County, South Dakota, 1971*

Ownership class	Stand-size class: Sawtimber	Stand-size class: Poletimber	Stand-size class: Seedling/sapling	Stand-size class: Nonstocked	Total
	- - - - - -	- - - - - -	M acres	- - - - - -	- - - - - -
Public:					
National Forest	182.7	64.4	8.7	6.8	262.6
Other federal	4.1	1.0	--	--	5.1
Total	186.8	65.4	8.7	6.8	267.7
State, county, and municipal	3.7	.7	--	--	4.4
Total	190.5	66.1	8.7	6.8	272.1
Private:					
Farm	30.4	6.3	--	--	36.7
Miscellaneous private[1]	23.7	5.6	--	--	29.3
Total	54.1	11.9	--	--	66.0
Total	244.6	78.0	8.7	6.8	338.1

[1]Includes land owned by forest industries.

NONCOMMERCIAL FOREST LAND

Farmers own 46 percent of the noncommercial forest land. Oak grows on most of the 55 percent of the noncommercial forest land. Ponderosa pine stands that are not capable of producing crops of industrial wood because of adverse site conditions (table 4) are found on 40 percent of the noncommercial forest land. The remaining 5 percent is in other softwoods.

Table 4.--*Area of noncommercial forest land by ownership class and forest type for Lawrence County, South Dakota, 1971*

Ownership class	Softwoods			Hardwoods		Total
	Ponderosa pine	White spruce	Other	Aspen	Other	
	M acres					
Public:						
National Forest	4.1	--	NS[1]	--	NS[1]	4.1
Other federal	.1	--	--	--	.3	.4
Total	4.2	--	NS	--	.3	4.5
State, county, and municipal	.3	--	NS	--	.6	.9
Total	4.5	--	NS	--	.9	5.4
Private:						
Farm	1.8	--	.6	--	5.9	8.3
Miscellaneous private[2]	.8	--	.4	--	3.0	4.2
Total	2.6	--	1.0	--	8.9	12.5
Total	7.1	--	1.0	--	9.8	17.9

[1]Not significant; less than 0.05 M acres.
[2]Includes land owned by forest industries.

DATA RELIABILITY

Total land area for Lawrence County was determined by a 100 percent map census and, therefore, has no sampling error.

Sampling error estimates were not available for the National Forest data presented, so the national accuracy standards prescribed in the Forest Service Handbook (4813.1, 11.1--1) were assumed: 3 percent per million acres on commercial forest land area, 10 percent per million acres on noncommercial forest land area, and 10 percent per billion cubic feet for volume. The Black Hills National Forest is not entirely included within Lawrence County; consequently, the sampling errors associated with the National Forest estimates may be either greater or less than the national accuracy standards.

On non-National Forest lands, forest land area and timber volume were estimated from a double sample using aerial photos for the area estimates and ground plots for the volume estimates. Sampling error estimates are 2.3 percent per million acres for commercial forest land area; 2.3 percent per million acres for noncommercial forest land area; 3.6 percent per billion cubic feet for total cubic-foot volume; and 8.0 percent per billion board feet for total board-foot volume.

TERMINOLOGY

Forest type.--Forested land classified according to plurality species of living trees.

FOREST SURVEY LAND CLASSES:

Commercial forest land.--Forest land that is producing or is capable of producing crops of industrial wood (20 cubic feet per acre per year).

Commercial forest land regulated.--Commercial forest land that is included in the allowable cut timber base.

Commercial forest land unregulated.--Commercial forest land that is not included in the allowable cut timber base because the timber occurs in isolated patches and stringers, unstable soils, and so forth.

Unproductive forest land.--Forest land that is not capable of producing crops of industrial wood (20 cubic feet per acre per year) because of adverse site conditions.

Productive reserved forest land.--Commercial forest land that has been withdrawn from timber production through statute or administrative regulation.

Nonforest land.--Land that does not support a forest cover.

STAND-SIZE CLASSES:

Sawtimber stands.--Stands at least 10 percent stocked with growing stock trees having a minimum net volume of 1,500 board feet (International ¼-inch rule) in sawtimber trees (9.0 inches diameter at breast height (dbh) and larger for softwoods and 11.0 inches dbh and larger for hardwoods).

Poletimber stands.--Stands failing to meet the sawtimber criteria, but at least 10 percent stocked with poletimber and larger trees (5.0 inches dbh and larger and at least the minimum stocking in poletimber size trees.

Seedling/sapling stands.--Stands failing to meet both the sawtimber and poletimber criteria, but having at least 10 percent stocking in trees of commercial species and with at least half the stocking in seedling and sapling size trees (less than 5.0 inches dbh).

Nonstocked areas.--A forest land area not qualifying for any of the above stand-size classes; i.e., usually an area of less than 10 percent stocking.

TREE SIZE CLASSES:

Growing stock trees.--All noncull trees 5.0 inches dbh and larger.

Sawtimber trees.--Softwood trees 9.0 inches dbh and larger and hardwood trees 11.0 inches dbh and larger.

VOLUMES:

Growing stock volume.--Net cubic-foot volume of all live merchantable trees 5.0 inches dbh and larger from a 1-foot stump to a minimum 4.0-inch top diameter outside bark.

Sawtimber volume.--Net International ¼-inch rule board-foot volume of live merchantable sawtimber trees.

U.S. GOVERNMENT PRINTING OFFICE: 1973 784-486 / 23 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-178

December 1973

RESISTANCE TO *CRONARTIUM RIBICOLA* IN *PINUS MONTICOLA*: STRUCTURE AND GAIN OF RESISTANCE IN THE SECOND GENERATION

R. J. Hoff, G. I. McDonald, and R. T. Bingham[1]

ABSTRACT

Nearly 66 percent of second generation (F_2) seedlings of western white pine, Pinus monticola, *were healthy 2-1/2 years after inoculation with the blister rust fungus,* Cronartium ribicola; *resistance to the pathogen about doubled that of the first generation (F_1). Although three resistance mechanisms were involved, most resistance was due to one, premature shedding of infected needles. Methods for incorporating all resistance mechanisms into a useful product are discussed. The percentage of healthy seedlings from a stand collection of eastern white pine,* Pinus strobus, *included for comparison, was about 5 percent.*

OXFORD: 174.7, 172.8
KEYWORDS: *Pinus monticola, Cronartium ribicola,* breeding methods, selection

Research and development toward production of western white pine *(Pinus monticola)* planting stock resistant to blister rust (*Cronartium ribicola*) has been underway since 1950. By 1957, it had become apparent that resistance is under genetic control and is transmissible from rare, rust-free "candidate trees" in rust-decimated stands to their control-pollinated, first-generation (F_1) offspring. Certain candidates were found to embody general combining ability (GCA) for resistance; that is, in a number of crosses, they imparted to their F_1 offspring a consistent above-average level of resistance. Furthermore, when two such "GCA-trees" were mated and the 2-year-old F_1 seedlings from the crosses were artificially inoculated with the rust, resistance of the F_1 was even higher. An average of about 30 percent more of these "GCA-F_1" seedlings withstood artificial exposure to *C. ribicola* than did seedlings from rust-infected trees in rust-decimated stands. Preliminary heritability (h^2) and genetic gain analyses indicated that besides the 30 percent gain from mating GCA-trees, we could expect another 20 percent plus gain from matings of resistance seedlings derived from GCA-trees; i.e., crosses of select F_1 seedlings to produce F_2 (Bingham and others 1960).

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[1]Principal Plant Geneticist, Principal Plant Pathologist, and Principal Plant Geneticist, respectively, stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, which is maintained in cooperation with the University of Idaho.

Subsequent progeny tests and more refined and precise h^2 and gain analyses (1960-1970) have given lower estimates of gain for the second generation. First-generation resistance, actually determined in the progeny tests, accrued both from natural selection by the rust and our artificial selection of GCA trees. This resistance remained nearly the same (average 24 percent) when GCA-F_1 seedlings were inoculated at 2 years (Becker and Marsden 1972), but when GCA F_1 seedlings were inoculated at 1 year, it dropped to about 12 percent (Bingham and others 1969). Similarly, estimated second-generation gains from mating resistant GCA-F_1 trees lowered drastically to about 3 percent (Bingham and others 1969), and sometimes to even less than 1 percent (Becker and Marsden 1972). To summarize, under selection for GCA, various progeny tests and h^2 and gain analyses have given three estimates of total gain from the original pre-blister rust population through the second generation of breeding, ca. 14 percent, 27 percent, and 50 percent.

These estimates were sufficiently encouraging for the USDA Forest Service to continue developmental work through selection for GCA among 400 candidate trees and establishment of orchards to mass-produce F_2 seed on resistant GCA-F_1 seedling foundation stocks. Meanwhile, it has been expedient to obtain experimental evidence as to actual gain through the second generation. Toward this end, we have been preserving rust-resistant GCA-F_1 seedlings from progeny tests since 1952. These F_1 trees are accumulated in a resistance-testing arboretum at Moscow, Idaho. Significant levels of female and male fruiting commenced when F_1's were about 10 and 15 years old, respectively. F_2 seed progenies, similar to those we expect from the seed orchards, were obtained by 1966 and sown in the Moscow resistance test nursery that fall.

More recently, we have found a genetic explanation for the resistance phenomenon termed "the spots-only syndrome." Here, foliar infections are not followed by the appearance of bark cankers. We hypothesize that resistance is controlled by two recessive genes acting sequentially in the needles (McDonald and Hoff 1971a,b; Hoff and McDonald 1971).

The purpose of this paper is to report the actual gain realized in artificially-inoculated F_2 seedlings produced under selection for GCA, and to show the kinds and proportions of resistance involved in this gain and ultimately in the F_2 seed orchards.

MATERIALS AND METHODS

Test materials reported upon here include almost 7,500 white pine seedlings representing 49 different control- or wind-pollinated progenies. The bulk of the seedlings are western white pines, but 100 seedlings from one wind-pollinated eastern white pine (*P. strobus*) progeny are included to permit a species comparison.

Susceptible western white pine progenies came from mixtures of seed from five or more heavily infected trees residual on six different, rust-decimated "selection areas" in northern Idaho and northwestern Montana. Six seed collections yielded 546 seedlings.[2] At the time seed was collected, these selection-area stands were nearly 100 percent infected and had already been reduced from 30 to 80 percent by rust-caused mortality. The F_1 progenies came from controlled pollinations of 20 relatively rust-free "candidate trees" in the same or similar selection areas. Ten crosses produced 2,876 seedlings. Both parents of the F_1 progenies had been previously progeny tested and rated as exhibiting general combining ability for resistance, as demonstrated by performance of four or more F_1 tester progenies (Bingham and others 1969). The F_2 progenies came from controlled pollination of 40 resistant F_1 trees in families where both natural-stand parents were rated as GCA trees. Thirty-two crosses produced 3,061 seedlings.

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[2]Two collections of seed were from squirrel caches, four lots were from wind-pollinated groups of five trees infected with blister rust.

Eastern white pine seedlings came from seed collected in one otherwise undescribed Michigan stand.

F_1 seed and seed from three susceptible lots were planted in three randomized complete blocks and grown in four nursery beds at a spacing of 2 by 2 inches. The F_2 crosses, susceptible lots, and the eastern white pine collection were planted in 10 randomized complete blocks in one bed, adjacent to the F_1 crosses; spacing was 1-1/2 by 1-1/2 inches.

The entire test was inoculated during September 1968 in one polyethylene-film chamber covered by canvas (Bingham 1972). The inoculum originated from blister rust-infected, telia-bearing leaves of *Ribes hudsonianum* var. *petiolare* from Hobo Creek, about 10 air miles northeast of Clarkia, Idaho. The leaves were arranged, telia down, in a dense layer covering about four-fifths of the surfaces of hardware cloth screens, placed 18 inches above the seedlings in the nursery beds. The interior of the chambers (including seedbeds and seedlings) was drenched with tapwater. The chambers were sealed to maintain relative humidity at 68 to 100 percent (except for 30 hours at 98 to 100 percent) at ambient temperatures (minimum 51°F maximum 84°F, mostly 60-70°F). The inoculation period was 116 hours.

Dates of inspections and results noted were as follows: June 1969, 9 months after inoculation, needle spots present; September 1969, 1 year after inoculation, needle spots and stem symptoms present; September 1970, 2 years after inoculation, stem symptoms present; March 1971, 2-1/2 years after inoculation, stem symptoms present. Seedlings that did not have spots 9 months after inoculations were not used in the data base; previous observations have indicated that under optimal inoculation levels and inoculation conditions nearly 100 percent of the seedlings have developed needle spots by this time (McDonald and Hoff 1971a).

The mechanisms of resistance that lead to rust exclusion were partitioned in the following manner.

1.--Premature shedding of infected needles. This mechanism is exemplified by seedlings that had needle spots 9 months after inoculation, but lost the infected needles within 12 months after inoculation. Consequently, the fungus was excluded before it reached the stem. It is hypothesized that this trait is controlled by a single recessive gene (McDonald and Hoff 1971a,b).

2.--Fungicidal short shoot reaction. This mechanism is exemplified by seedlings that had needle spots 9 and 12 months after inoculation, but no cankers nor other stem symptoms (such as bark reactions) developed. Apparently, no stem symptoms developed because the fungus was killed in the short shoot or contiguous stem tissues (Hoff and McDonald 1971). It is hypothesized that this trait is controlled by a single recessive gene (McDonald and Hoff 1971b).

3.--Bark reactions or reactions in the stem that apparently cause the death of the fungus. Seedlings in this category had needle spots at 9 and 12 months. Then, at 12, 24, or 30 months after inoculation, they produced (a) typical, discolored bark cankers along with bark reactions or (b) bark reactions alone. Apparently, the reaction had somehow killed the fungus. The genetics of this trait are unknown, but the reactions can be placed into definite categories, an indication that only a few genes may be involved.

RESULTS

Pinus monticola

The percentage of uninfected F_2 seedlings 2-1/2 years after inoculation was about 66 percent (table 1). When compared to the percentage of uninfected F_1 seedlings in the same test, a gain of about 33 percent was realized (table 2). Also, the gain between the selected F_1 parents and the susceptible lots was substantial (nearly 14 percent).

The level of resistance in the susceptible *P. monticola* lots was about 19 percent. However, there is good reason to believe that the greatest part of this resistance comes from intense natural selection in the high-rust-mortality selection areas. Although there is little information as to the amount of resistance in populations of western white pine that have had no mortality attributed to blister rust, available data indicate that only 3 to 5 percent of the progeny from such stands would be free of cankers (Mielke 1943; U.S. Dep. Agric. 1966). If these percentages are appropriate, the realized gain[3] between a remnant population and a population before any rust mortality might account for most of the 14 to 16 percent difference.

Resistance data (Bingham and others 1960; Bingham and others 1969; and Becker and Marsden 1972) were based on the percentage of healthy seedlings; i.e., on seedlings that somehow withstood rust and were not diseased 2 or more years after inoculation. However, we now believe that there are several resistance genes and mechanisms of resistance in western white pine, any one of which can result in healthy seedlings. Consequently, we are interested in determining how the frequency of various genes or mechanisms of resistance is affected when selection for GCA is based on a percentage healthy criterion.

Tables 1 and 2 show that most of the gain in the susceptible lots in the F_1 and F_2 was due to the premature needle-shedding mechanism. The percentage gain of the F_1 selections above the susceptible lots was nearly equal for the three resistance mechanisms (table 2); however, the increase of the premature needle-shedding trait from the F_1 to the F_2 generation appeared to be very large when compared to the other mechanisms of resistance.

Since we have hypothesized that the first two resistance mechanisms are controlled by single recessive genes, we can look at the genetic gain by determining the frequency of the genes. The gene frequency for both the premature shedding and the fungicidal short shoot gene is the square root of the proportion of healthy seedlings of each factor. For the premature shedding gene, the gene frequency is 0.38 for the susceptible lots, 0.45 for the F_1 generation, and 0.69 for the F_2 generation. For the fungicidal short shoot gene, the gene frequency is 0.15 for the susceptible lots, 0.25 for the F_1 generation, and 0.47 for the F_2 generation. Therefore, the genetic gain from the susceptible lots to the F_2 generation is about equal.

Pinus strobus

Unselected *P. strobus* exhibited a low level of resistance (table 1); we observed only two of the resistance traits, premature needle shedding and bark reactions. Also, the amount of mortality was very high (79.8 percent) compared to that of western white pine (average mortality for all crosses was 14.2 percent).

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[3]Following intense natural selection after 80-90 percent rust mortality.

Table 1.--*The level and the mechanisms of resistance of* Pinus monticola *and* P. strobus *to white pine blister rust 2-1/2 years after inoculation*

Species	Type of parentage	Lots or crosses	Total seedlings	Seedlings uninfected	Mechanism of resistance: Premature shedding of infected needles	Mechanism of resistance: Fungicidal short shoot	Mechanism of resistance: Bark reaction	Killed by blister rust	Seedlings with no spots nor stem symptoms (probable escapes)[1]
		No.	*No.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*No.*
P. monticola	Susceptible	6	546	18.9	14.5	2.0	2.4	17.8	23
	F_1	10	2,876	32.7	19.9	5.2	7.7	13.8	35
	F_2	32	3,061	65.8	47.4	11.5	6.9	7.0	462
P. strobus	P_s	1	99	5.0	3.0	0	2.0	79.8	0

[1]These seedlings were not included in the data base. They are included here just to indicate the level of "disease escape" in this test.

Table 2.--*Resistance and realized gain in resistance to white pine blister rust in various lots and/or crosses in* Pinus monticola

Resistance category	Resistance: Susceptible lots	Resistance: F_1	Resistance: F_2	Realized gain: From susceptible to F_1	Realized gain: From F_1 to F_2 generation
	Percent				
Total seedlings uninfected	18.9	32.7	65.8	13.8	33.1
MECHANISMS OF RESISTANCE					
Premature shedding	14.5	19.9	47.4	5.4	27.5
Fungicidal short shoot[1]	2.4	6.5	21.9	4.1	15.4
Bark[1] reaction	2.9	10.3	16.8	7.4	6.5

[1]Corrected for the number of resistant seedlings due to the previous mechanism(s) of resistance.

DISCUSSION

Nearly 66 percent of the western white pine seedlings from the F_2 generation that exhibited needle infections were uninfected 2-1/2 years after inoculation. This increase (about 33 percent) over the F_1 generation was a much higher gain in resistance than had been predicted. A ready explanation for this rapid gain is that the two main mechanisms of resistance involved are controlled by single genes. On the other hand, if these single genes are recessive, as we have hypothesized, then an even greater gain should have been realized. In fact, since we hypothesized that certain mated F_1 parents were likely to be homozygous for one or the other of the recessive resistance genes, we should have seen some families that were 100 percent resistant. However, the highest resistance observed was only 88 percent. Even though the F_1 parents were selected 15 years ago--long before the single genes were hypothesized--we found this figure somewhat disappointing; we had hoped the F_2 data would confirm our hypotheses concerning single genes.

We can propose several reasons why certain of the F_2 progenies did not have as high a resistance as we predicted on the basis of the single-gene-controlled traits:

1.--F_1 parents that had the same homozygous recessive genome were not included in the random crosses, which seems unlikely since most of the resistance was due to one gene (premature shedding). Also, in the F_2's from F_1 selfing (only three progenies in the test), the pattern of resistance reflected the F_2 data for progenies from outcrossed F_1's.

2.--One report indicates that the two needle resistance mechanisms can be bypassed by direct penetration of the stem; Van Arsdel (1968) successfully inoculated very tender young shoots of eastern white pine. However, direct penetration of stems has never been demonstrated on *P. monticola* here in Moscow in 20 years of progeny testing.

3.--The inoculated 2-year-old seedlings may have borne some primary foliage that is relatively much more susceptible. *P. monticola* seedlings inoculated at 1 year are highly susceptible compared to seedlings from the same or similar type cross inoculated at 2 years (Bingham 1972). At the time of inoculation, the main morphological difference between the two age groups is the presence of mostly primary needles on the 1-year-old seedlings and mostly secondary needles on the 2-year-old seedlings. However, there is often some primary foliage on normal 2-year-old seedlings. These simple leaves also are produced on seedlings 2 years old or older because of mechanical injury or physiological disturbances on lammas growth.

4.--The genes are not completely recessive. This fact should also explain why susceptible lots contained a relatively high number of seedlings carrying the genes that controlled the premature needle-shedding and fungicidal short shoot traits.

5.--New pathogenic races.

Determination of the complete genetic structure of blister rust resistance in western white pine must await further research. Meanwhile, breeding for resistance need not be delayed. Rapid progress can be made by using the system of selection for GCA proposed by Bingham, Squillace, and Wright (1960). However, this somewhat "blind" selection could result in the situation encountered in the experimental F_2 progenies reported in this paper; i.e., about 70 percent of the apparent resistance is controlled by the single recessive needle-shedding gene. For this reason, we propose that a more conservative selection method be used. More often than not, single gene resistance is overcome by new pathogenic races.

We propose that the selection be based on individual mechanisms of resistance and that an effort be made to incorporate as wide a range of mechanisms as possible into the new resistant populations. In this paper, we have discussed three mechanisms. Two of these appear to be typical vertical resistance factors, expressed as major gene inheritance and exclusion of the rust. The third (bark reactions) also excludes the rust eventually, often after 2 or 3 years, but inheritance seems to be oligogenic or possibly polygenic. In addition, several other resistance mechanisms have been observed in western white pine (Bingham and others 1971; Hoff and McDonald 1972). Some of these are race specific, others are horizontal resistance mechanisms; e.g., fewer needle spots, slow fungus growth. At present, we would advocate incorporating all these forms of resistance, emphasizing horizontal resistance mechanisms as much as possible.

In 1971, seed orchards for rust-resistant western white pine were started near Coeur d'Alene, Idaho. The selection method used was based on individual mechanisms of resistance. An effort was made to select equal numbers of seedlings (from many crosses) showing premature needle shedding, fungicidal short shoot, and bark reactions. When possible, seedlings were also chosen because they exhibited fewer needle spots and were from low-needle-spotting families or were from families that exhibited other horizontal resistance factors. Seed from these orchards should contain a fair amount of genetic variability for resistance at a level useful for artificial regeneration of western white pine.

The eastern white pine seed lot included in the test was found to be highly susceptible. Although we have no information concerning the history of this stand collection, we can assume either that the stand had not been reduced by blister rust mortality or that resistance did not hold up in a new environment. We favor the first explanation. From time to time, we have tested several other species of white pine that were ranked as being highly resistant; they have retained their resistance in our tests.

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Research Note
UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-179

December 1973

BREEDING BLISTER RUST RESISTANT WESTERN WHITE PINE. VI. FIRST RESULTS FROM FIELD TESTING OF RESISTANT PLANTING STOCK

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ABSTRACT

Twenty- to 36-acre pilot-scale tests for determination of "field" resistance in blister rust resistant western white pine have been established in three localities in northern Idaho and northeastern Washington. The F_1, B_1, and F_2 planting stocks represent, respectively, one, one and one-half, and two cycles of selection for general combining ability for resistance. Preliminary results from the first-planted, 36-acre test, following natural exposure to the rust for 2 years, in a locality of extremely high blister rust hazard, showed nonresistant control stock 76 percent infected, with 2.66 cankers per infected tree. The F_1's were 31 percent infected, with 1.56 cankers per tree; B_1's, 24 percent infected, with 1.45 cankers; and F_2's 12 percent infected, with 1.19 cankers. Companion experimental tests of similar F_1 and F_2 progenies artificially inoculated at age 2 years in the rust nursery showed that at 30 months after inoculation F_1's were 67 percent infected, F_2's 34 percent infected. Thus, field tests were confirmatory of nursery tests. There is good expectation for attaining similar, and probably longer lasting performance, in F_2 planting stocks soon to come from production F_2 seed orchards now in the process of establishment.

OXFORD: 165.4, 165.62
KEYWORDS: breeding methods (plant), selection (artificial), disease resistance, western white pine (*Pinus monticola*), white pine blister rust (*Cronartium ribicola*)

[1]Research Geneticists and Pathologist (McDonald) stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

BACKGROUND

Since 1950, a research and development program toward production of blister rust resistant western white pine planting stock has been conducted by the Intermountain Station and the Northern Region. Progress of the work has been reported from time to time.

Bingham (1954) covered first results in 60 first-generation (F_1) progenies from crosses between rust-free "candidate trees" found in rust-decimated natural stands. The 2-year-old progenies were artificially inoculated. Proportion of seedlings with foliar infections ranged from 47 to 97 percent, and the frequency of needle lesions from 37 to 402 per 450 needles. By 1957, following the single inoculation, and after the rust had fairly well run its course in these F_1 progenies, Bingham, and others (1960) showed that resistance was definitely seed transmissible--from rust-free candidates to F_1 offspring. They also showed that about one in four candidates tested had general combining ability (GCA) for resistance, that is, they consistently transmitted above-average levels of resistance to a number of their F_1 progenies. Furthermore, when two such GCA trees were mated, about 30 percent of the seedlings in the resulting GCA-F_1 progenies somehow withstood the intense, artificial exposure to the rust. Three or more possible mechanisms and seats of resistance were recognized: (1) a mechanism that reduced the number of stomatal penetrations or prevented establishment of rust mycelium in the needles; (2) a mechanism(s) that prevented rust mycelium from invading or establishing itself in branch or stem bark from infected needles; and (3) a mechanism(s) in the bark that eliminated the rust after successful invasion of the stem.

Our first results on field resistance were reported by Steinhoff (1971). He showed that after 11 to 15 years exposure to apparently moderate, natural blister rust inoculation on two experimental forest field plots in northern Idaho, 40 small GCA-F_1 progenies became 20 percent infected, planted controls 58 percent infected, and naturally reproduced white pines of about the same age 71 percent infected.

Early heritability and genetic gain analyses (Bingham and others 1960) were favorable. Heritability (h^2) of resistance was estimated at about 70 percent, and substantial gains of about 20 percent were forecast should selection for GCA proceed through a second cycle of breeding. Thus, F_2 progenies bred from tested, resistant GCA-F_1 trees should approach 50 percent resistance. Cooperators accepted this predicted level of resistance as sufficient for a first-stage program in which F_2 planting stock would be produced in F_1 seedling orchards.

A period of intensified developmental work followed in 1960-1972. Cooperators screened 400 candidates for GCA, and selected the best 24 GCA-trees in each of the low-, mid-, and high-elevation planting zones for the species. Then they remated pairs of the 24 GCA trees from each zone, thus producing 12 large GCA-F_1 families per zone. Finally, they artificially inoculated the 36 families, selecting sufficient numbers of resistant, GCA-F_1 seedlings to establish 12-family seedling seed orchards for each elevational zone. Now, 13 acres of low-elevation orchard, 20 acres of mid-elevation orchard, and 7 acres of high-elevation orchard--acreage varying according to anticipated National Forest planting-site elevations--are being established near Coeur d'Alene, Idaho. Significant production of F_2 seed is anticipated about 1985.

Thus results from nursery and field testing of F_2 seedlings are of particular importance to the Station-Region first-stage program. The F_2 tests are proceeding in two places: (1) in the blister rust nursery, under artificial inoculation, at Moscow, Idaho; and (2) on 20- to 36-acre pilot-scale field plantings, under natural inoculation, on three nearby National Forests in northern Idaho and northeastern Washington. Results from (1), above, have been reported by Hoff and others (1973). The present Research Note describes the earliest preliminary results from a field plot planted in 1970 on the St. Joe National Forest.

MATERIALS AND METHODS

The results reported here are from a study entitled "Field Level of Resistance in Stocks from Early-Generation Breeding" and including F_1, F_1 backcross, and F_2 progenies, as well as local-origin, nonresistant control seedlings. Combinations of all of these early-generation progenies were planted in two identically designed, 36-acre field plots, one on the St. Joe National Forest near Clarkia, Idaho (1970, West Fork, Merry Creek) and one on the Colville National Forest near Newport, Washington (1971, Gletty Creek). One 20-acre planting, using only F_2 and local control progenies in mixed-species plantings with local Douglas-fir and grand fir, has also been established on the Clearwater National Forest near Pierce, Idaho (1972, Jaype). Materials, methods, and results given below apply only to the 36-acre field plot on the St. Joe National Forest.

Seed, Pregermination Treatment, and Nursery Sowing

Since 1950, surplus seeds from many different early-generation crosses have been stored in airtight containers at 35° to 40° F at our Moscow, Idaho, laboratory. This seed is of three types: F_1, from crosses between two natural-stand GCA trees; B_1, from crosses between 10- to 15-year-old resistant GCA-F_1 arboretum trees as seed parents and nonrelated natural-stand GCA trees as pollen parents (that is, $P_1 \times P_0$ backcrosses), or F_2, from crosses between two nonrelated resistant GCA-F_1 trees in the arboretum. The three types of "resistant" seed thus represent results of one, one and one-half, and two cycles of selection for GCA.

Three bulked seed lots representing the three kinds of resistant seed were compounded for the St. Joe National Forest field plot by mixing from 40 to 80 individual seed lots. These bulks, along with a nonresistant control seed lot, are characterized in table 1.

Table 1.--*Composition of bulked seed lots field tested on St. Joe National Forest plot*

Type of bulk	Individual lots included	Seeds per lot, range	Total seed	Parentage: GCA trees	Parentage: CGA-F_1 families	Parentage: Trees per family, range	Crosses of different pedigree represented	Selection areas represented	Elevation range, GCA trees
									Feet
F_1	61	16-1,303	20,038	30			61	12	2,675-4,100
B_1	83	3-765	15,019	13	27	1-7	40	4	3,020-3,200
F_2	43	2-2,318	9,997	9	18	1-6	34	4	3,020-3,200
Control	[1]1								

[1]U.S. Forest Service Northern Region, seed lot 18-0-119-4, St. Joe National Forest origin.

After brief infrared irradiation (cf. Works and Boyd 1972), the three resistant seed bulks were "naked-stratified" in covered flasks at 35° to 40° F, for 50 days during April and May 1967. At the end of May, seed was broken out and dusted with 50 percent wettable Captan, then surface dried. Each bulk was divided into 30 roughly equal parts by weight and then returned to the refrigerator in small polyethylene bags. The next day, seed was transported to the Forest Service nursery at Coeur d'Alene, Idaho, and carefully broadcast sown. Spacing was close to 2 by 2 inches. Sowing was in three randomized complete blocks making up one 315-foot-long nursery bed. (The bed had been fumigated with methyl bromide:chloropicrin, 2:1.) To secure seed spacing, bedspace allotted to a given bulk in each block was divided into 10 equal parts, and the seed from one of the 30 polyethylene bags was sown in each of the 30 parts of the nursery beds. For the control group, 1-year-old plants in a standard nursery bed at the Forest Service's former Savenac Nursery at Haugan, Montana, were used. The plants were raised from the only available St. Joe National Forest seed of the same geographic and elevational zone as the proposed outplanting area, sown in fall 1965. We elected to use this 1-year-older stock rather than risk maladaptation possibly associated with use of control stock from a different geographic or elevational zone.

Nursery Tending, Lifting, and Planting

Stock remained in the two nurseries under routine fertilizing and overhead irrigation regimes through spring 1970. By then the three resistant stocks were 3-0 age, and about to commence their fourth season of growth; control stock was 4-0, and entering its fifth season. Early in April, seedlings were undercut, lifted, root-pruned to 12 inches, bundled, counted, tagged, packaged in polyethylene-treated cardboard boxes with moist sphagnum moss around the roots, and stored in the seedling storage refrigerators at Coeur d'Alene. Packaged stock was delivered by refrigerated truck to the Clarkia Ranger Station, Clarkia, Idaho, on May 4, 1970, and stored there in a walk-in refrigerator at 40° F until outplanted May 5 to 21.

The 36-acre planting area in the West Fork of Merry Creek (about 4 miles NNE. of Clarkia, Idaho, mean elevation about 3,600 feet) had been clearcut and burned in the fall of 1968. In the experimental design used in planting (fig. 1), there are three 3- by 4-acre blocks (A, B, and C), and within each block there are three 1- by 4-acre replicates (1, 2, and 3). Each replicate contains one acre-sized planting (210 by 210 feet) of each of the resistant and control stocks. Spacing of planting stock varied from 7 by 7 feet to 9 by 9 feet (fig. 1), depending on the expected rust mortality of the different resistant stocks, or the amount of control stock available. In each acre planting, the North-South rows of trees were planted in almost perfectly straight rows, using portable, stretchable, bungee-cord lines to mark the row while it was planted. Under the bungee-cord line, holes 12 inches deep and 4 inches wide were bored with a gasoline-powered planting auger. Color-coded tape markers were used on the cord at 7-, 8-, or 9-foot intervals; holes were allowed to vary up to 2 feet either way along the line from the markers, but not to left or right of the line. This procedure was followed to insure that planted white pines would be distinguishable from naturally reproduced white pines for many years.

After root pruning, the three types of resistant planting stock had a normal (about 2:1) root:shoot ratio, but the 1-year-older control stock from more crowded nursery beds had somewhat "leggy" tops, fewer fibrous roots, and more tap roots. Less than 1 percent of the 23,700 planting spots on the 36-acre plot (180) were not planted; about three-fourths of the unplanted spots were in swampy areas, and one-fourth under logs or stumps lying along the straight planting lines.

In September 1972, permanent sample trees were chosen, tagged, and examined. In each acre area, 25 trees were chosen in four clusters of six or seven trees. The

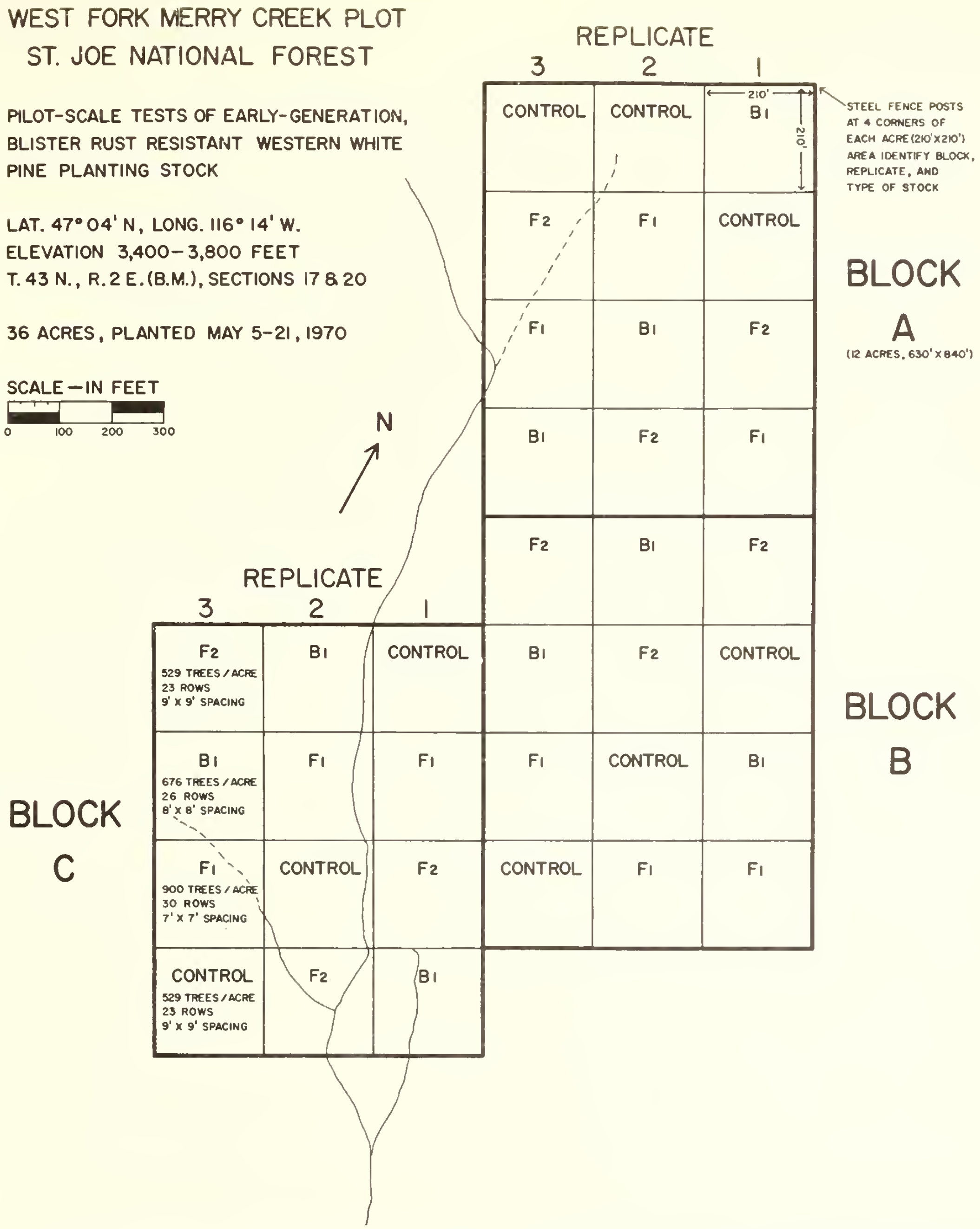

Figure 1.--The 36-acre field test planting, consisting of three randomized blocks.

cluster center was the planting spot three rows and tiers into the acre plot, at each corner. Thus, in each 4-acre replicate there were 100 sample trees, making 225 sample trees per stock type, 300 per block, and 900 total. Data recorded for each sample seedling were (1) planting row and tier (row 1 tier 1 being the position nearest the acre's northwest corner post); (2) height in centimeters; and (3) the number of stem and the number of branch cankers.

One year after burning (fall 1969), a very heavy crop of seedlings of the sticky currant (*Ribes viscosissimum* Pursh) was present on the area. During planting (spring 1970), it was noted that these plants had persisted and were particularly abundant along the ridges. The largest currant plants were then 35 cm tall and had up to 125 cm of live stem. By the time of sample-tree examination (fall 1972), the largest currant plants were 75 cm tall, with 250 to 300 cm of live stem. *Cronartium ribicola* J. C. Fisch. ex Rabenh., in the uredial or telial stage, was observed to be abundant on undersides of the currant leaves in both 1970 and 1972.

RESULTS

Planting Survival

Checked in late September 1970 after the first summer, which was somewhat rainy and thus favorable for seedling establishment, survival in the four types of stock was, for controls, 62 percent; F_1's, 93 percent; B_1's, 82 percent; and F_2's, 92 percent. This left about 9,750 planted trees on the 36 acres.

Blister Rust Infection

The 1972 inspection yielded means for each of the thirty-six 25-tree or acre samples as shown in table 2. A glance at these basic data, and at the grand means (table 3), shows the relatively wide range of variation in rust intensity, and possibly seedling height, associated with blocks, replicates, and stock types. The main differences emerging after only 2 years of natural rust exposure seem to be associated with type of planting stock. For example, control stock is much more heavily infected than are the three resistant stocks (table 3). Sixty-four percent more (six times as many) control seedlings than F_2's are infected, and these infected plants bear 2.2 times as many cankers as infected F_2 plants. Fifty-two percent more (three times as many) controls than B_1's are infected with 1.8 times more cankers per infected tree; and 45 percent (two and one-half times as many) more controls than F_1's are infected, with 1.7 times more cankers per tree.

The analysis of variance (table 4) shows that stock types differ significantly in percent infection and numbers of cankers per infected or sample tree. Also, there are significant stock type X block interactions affecting cankers per tree, or height of healthy trees. This might be expected in view of the epidemiological and silvical contrasts that could occur between such large (12-acre) blocks. The Scheffé S-contrast test (table 5) shows that there is significant variation among the four stock types. Controls are significantly more heavily infected than the three resistant stocks, and F_1 stock is significantly more heavily infected than F_2 stock.

Seedling height was considered because there may be positive correlation between height (an indirect measure of foliation, or target area presented to airborne rust basidiospores) and the number of blister rust cankers per tree. This relationship has been suggested for both western and eastern white pines (Childs and Kimmey 1938; Filler 1933). In fact, when a correlation analysis is applied to the data of Childs and Kimmey (1938, table 4) for mean tree height vs. average number of cankers per tree, a high correlation of these two variables ($r = 0.976$, significant at the 1 percent level of probability) is evident. It seems likely that a similar relationship holds for unpublished individual-tree data of the above report. Thus it is a tenable assumption that environmentally or genetically controlled increases in tree height may be accompanied by increases in the number of cankers per tree. It is pertinent to investigate any extraneous differences in tree height that might be associated with sample tree age (controls are 1 year older), with rate of height growth between the genetically different types of stock, or with blocks and replicates within blocks.

Table 2.--*Mean blister rust infection and tree height in the field test plot, St. Joe National Forest, by type of planting stock, blocks, and replicates*[1]

Type of stock, block, and replicate	Infection per 25-tree sample	Total cankers on infected trees	Average cankers per infected tree	Average cankers per sample tree	Height of average infected tree	Height of average healthy tree
	Percent				- - - - *Cm*	- - - -
Control						
A1	92	58	2.52	2.32	34.3	30.0
A2	96	73	3.04	2.92	42.0	40.0
A3	88	79	3.59	3.16	46.9	40.0
B1	64	38	2.38	1.52	35.9	33.0
B2	76	34	1.79	1.36	33.6	37.7
B3	48	21	1.75	0.84	37.8	37.2
C1	88	53	2.41	2.12	42.6	38.5
C2	72	65	3.61	2.60	41.2	41.5
C3	60	43	2.87	1.72	34.5	33.6
F_1						
A1	16	6	1.50	0.24	50.2	42.7
A2	40	19	1.90	0.76	39.3	43.1
A3	56	37	2.64	1.48	46.9	45.0
B1	28	10	1.43	0.40	38.6	32.9
B2	28	7	1.00	0.28	36.6	37.7
B3	20	7	1.40	0.28	45.2	40.7
C1	36	9	1.00	0.36	38.6	34.4
C2	48	19	1.68	0.76	38.5	28.8
C3	8	3	1.50	0.12	43.0	35.8
B_1						
A1	8	3	1.50	0.12	37.5	35.9
A2	36	14	1.56	0.56	28.3	35.6
A3	32	14	1.75	0.56	37.6	34.9
B1	20	10	2.00	0.40	48.2	39.1
B2	28	10	1.47	0.40	37.0	44.1
B3	20	4	1.00	0.16	32.3	35.1
C1	12	3	1.00	0.12	44.5	41.4
C2	28	11	1.57	0.44	35.0	35.5
C3	36	11	1.22	0.44	38.6	34.4
F_2						
A1	12	3	1.00	0.12	28.7	29.7
A2	12	3	1.00	0.12	37.0	27.6
A3	24	10	1.67	0.40	33.6	33.5
B1	8	3	1.50	0.12	61.0	37.2
B2	28	11	1.57	0.44	37.9	36.4
B3	4	1	1.00	0.04	48.0	37.5
C1	4	1	1.00	0.04	32.0	31.4
C2	4	1	1.00	0.04	49.0	33.3
C3	12	3	1.00	0.12	44.0	33.0

[1]Data cover 25 sample trees from each acre of plantation.

Table 3.--*Grand means for blister rust infection and tree height according to blocks, replicates, and stock types, field test, St. Joe National Forest*

Variable	Infection per 25-tree sample	Angle = arcsin $\sqrt{\%\ \text{inf.}}$ [1]	Cankers per infected tree	Cankers per sample tree	Height of average infected tree	Height of average healthy tree
	Percent				- - - - *Cm*	- - - -
Blocks						
A	42.7	40.89	1.97	1.06	39.9	36.5
B	30.7	32.76	1.52	0.52	38.2	37.4
C	34.0	34.01	1.66	0.74	39.1	35.1
Replicates						
1	32.3	33.36	1.60	0.66	39.4	35.5
2	41.3	39.73	1.76	0.89	37.7	36.8
3	33.7	34.57	1.78	0.78	40.8	36.7
Stock types						
Control	76.0	62.00	2.66	2.06	38.8	36.8
F_1	31.1	33.21	1.56	0.52	41.9	37.9
B_1	24.0	29.10	1.45	0.36	37.7	37.3
F_2	12.0	19.24	1.19	0.16	41.2	33.3
Overall means	35.7	35.88	1.72	0.77	39.9	36.3

[1]Transformation of percentage (binomial) data recommended by Bartlett (1936) to stabilize variances, and used in analyses of tables 4 and 5.

Table 4.--*Significance of overall differences for stock types, block, and replicates by analysis of variance, field test, St. Joe National Forest*

Source of variation	MS[1] tester	Degrees of freedom	Angle = arcsin $\sqrt{\%\ \text{inf.}}$ MS	Angle = arcsin $\sqrt{\%\ \text{inf.}}$ F[2]	Cankers per infected tree MS	Cankers per infected tree F	Cankers per sample tree MS	Cankers per sample tree F	Height of average infected tree MS	Height of average infected tree F	Height of average healthy tree MS	Height of average healthy tree F
									Cm	Cm	Cm	Cm
1. Blocks	2.	2	228.18	1.996	0.561	1.276	0.896	3.588	19.12	0.483	15.42	1.468
2. Replicates within blocks	6.	6	114.33	0.337	0.440	0.829	0.250	0.323	39.60	0.885	10.50	0.564
3. Stock types	4.	3	3036.24	40.132**	3,786	9.713*	6.828	17,209**	35.75	0.438	38.92	0.969
4. Stock type X blocks	5.	6	75.66	1.168	0.390	6.168**	0.397	8.000*	81.52	2.115	40.16	3.608*
5. Stock type X replicates within blocks	6.	18	64.76	0.190	0.063	0.119	0.050	0.064	38.55	0.861	11.13	0.597
6. Total		35	339.16		0.531		0.773		44.75		18.63	

[1]Mean square.
[2]Fisher's variance ratio.

*Significant at the 5 percent level of probability.
**Significant at the 1 percent level of probability.

Table 5.--*Significance of differences between pairs of stock type means by the Scheffé (1959) S-contrast test, field test, St. Joe National Forest*

For difference between			F, Fisher's variance ratio				
			Angle = arcsin $\sqrt{\%\text{ inf.}}$	Cankers per infected tree	Cankers per sample tree	Height of average infected tree	Height of average healthy tree
						Cm	*Cm*
Control	and	F_1	14.405**	8.020**	17.336**	0.316	0.108
		B_1	18,811**	9.704**	21.126**	0.040	0.022
		F_2	31.776**	14.323**	26.389**	0.190	1.099
F_1	and	B_1	0.294	0.802	0.187	0.580	0.032
		F_2	3.392*	0.907	0.947	0.016	1.898
B_1	and	F_2	1.690	0.448	0.292	0.403	1.435

*Significant at the 5 percent level of probability.
**Significant at the 1 percent level of probability.

The analysis of variance (table 4), however, shows that there are no significant relationships of tree heights with blocks, replicates, or stock types. Height of the average healthy (but not infected) tree is significantly affected by interaction of stock type and block. Similarly, the Scheffé test shows no significant differences in height across the four stock types. Finally, to examine more directly the possible relationship between seedling height and cankering, the individual infected-tree heights and numbers of cankers were used in correlation analyses for each of the four stock types. The results were:

Stock type	*Infected trees*	*Correlation coefficient (r)*
Control	152	0.245**
F_1	69	.234
B_1	50	-.124
F_2	24	-.132

**Significant at 1 percent level of probability.

The low, or nonsignificant correlation coefficients provided by these latter analyses tend to support the interpretation arrived at from results of the analysis of variance and Scheffé S-contrast tests--that is, there is a general uniformity of tree heights, thus lack of extraneous height effects, across blocks, replicates, and stock types.

DISCUSSION AND CONCLUSIONS

Hoff and others (1973) demonstrated that in nursery trials where progenies were artificially inoculated at 2 years of age, 90 to 100 percent of the seedlings developed foliar infections. However, 30 months later 33 percent of the GCA-F_1, and 66 percent of the GCA-F_2 seedlings were free of rust. What is the equivalence of such "rust nursery resistance" and "field resistance" that would be apparent after long-continued exposure of GCA-F_1's and F_2's to natural inoculation in the forest? The Note by Steinhoff (1971) covering 40 small GCA-F_1 progenies exposed in two field plots to moderate levels of natural inoculation, reported that GCA-F_1's performed well after 11 to 15 years of exposure.

Newer information from large F_1, B_1, and F_2 progenies given here is even more encouraging. At this early date, resistant progenies show excellent performance in a single, 36-acre high-rust-hazard area. After 2 years of natural exposure to blister rust, 88 percent of the F_2's, 76 percent of the B_1's, and 69 percent of the F_1's, but only 24 percent of the controls, remain free of rust. Progressive accumulation of resistance from one cycle (F_1's), one and one-half cycles (B_1's), and two cycles (F_2's) of selection for general combining ability is apparent. The accumulated resistance may of course prove transient if rust race population structure changes, and it may diminish substantially between juvenile and rotation age. If not, however, the F_2 stocks soon to come from the Coeur d'Alene seed orchards will indeed be useful.

Two indications of the probable stability of rust resistance should be noted. First, on the forest areas where parental candidates are located, blister rust has been present about 45 years. Candidates found to be free of rust up to 1950 have remained so. Thus far, no visible changes in the rust population have occurred, despite intense natural selection proceeding in northern Idaho forests. In addition, seed orchard F_2's will probably have a more stable genetic base in resistance than the field-tested F_2's discussed here, which were developed under "blind" selection for GCA. That is, resistant GCA-F_1 foundation stocks were selected merely because they survived intense, artificial exposure to the rust. They were crossed in the arboretum without knowledge of the kinds or numbers of resistance genes and reactions they might represent. One result of this blind selection, as Hoff and others (1973) have shown, was that about seven-tenths of the resistance apparently came from a single, immunity-imparting recessive gene. They pointed out, however, that proportions of resistance owing to this or to other major or minor genes in the F_2, could be substantially altered, or equalized, through use of newer information when selecting resistant F_1 foundation stocks for seed orchards. This newer information on foliar and bark resistance genes and reactions was utilized in selection of the Coeur d'Alene orchard foundation stocks. Presumably, the more broadly based F_2 stocks to come from these orchards will embody more stable resistance than the blindly selected F_2's now being field-tested.

On this basis, can we conclude that the blister rust problem is solved for western white pine? For the time being the answer has to be "no." The first-stage, resistant F_2 stock (potentially about 65 percent resistant) appears to be a good *first* product--one that has good possibility for restoring the silviculturally tractable and valuable western white pine as a manageable component of the ecosystem for a rotation or more. Nevertheless, we realize that we now must work toward stabilizing resistance. Cooperators in this breeding venture agree that first-stage F_2 seed should not be planted for more than about 20 years, and then only in mixed plantings with other competitive, native species. Accordingly, first-stage seed orchards planned to meet all Northern Region National Forest requirements for western white pine are relatively small (40 acres). With mixed species planting, these orchards will provide seed for planting 15,000 to 20,000 acres per year.

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U.S. GOVERNMENT PRINTING OFFICE: 1974 — 784-489 / 47 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-180

January 1974

FLIGHT AND ATTACK BEHAVIOR OF MOUNTAIN PINE BEETLES IN LODGEPOLE PINE OF NORTHERN UTAH AND SOUTHERN IDAHO

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ABSTRACT

*Temperature appears to be the most important factor influencing flight and attack behavior of the mountain pine beetle (*Dendroctonus ponderosae *Hopk.). To a large extent, temperature governs onset, daily time and length of emergence and flight, and the location of initial attack. The optimum temperature range for adult mountain pine beetle activity extends from about 19°C to about 32°C; higher or lower temperatures limit beetle activity. Even though the sex ratio of attacking beetles favored the female in this study, all females were mated within at least 10 days of a mass attack on lodgepole pine (*Pinus contorta *Dougl.). Mated females constructed galleries at a greater rate than unmated females.*

Infestations of the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) have long been a part of the lodgepole pine (*Pinus contorta* Dougl.) forests of the intermountain area.

Factors influencing the flight and attack behavior of *Dendroctonus* beetles have been investigated by many workers (Rudinsky and Vité 1956; Miller and Keen 1960; Gara and Vité 1962; Atkins 1966); however, much remains to be learned about the behavior of the mountain pine beetle.

Flights and attacks of these beetles were observed for three consecutive summers (1970-1972) in lodgepole pine stands of northern Utah and southern Idaho. Study areas contained sufficient numbers of trees of large diameter to sustain active and increasing beetle populations. Observations of beetle behavior were confined to a single location within each infestation area. Daily observations were begun as soon as beetle emergence and attacks were in process and lasted until the flight period had ceased.

FLIGHT BEHAVIOR

Influence of temperature.--Emergence and flight of *Dendroctonus ponderosae* usually began in late morning when the air temperature had risen to about 19°C and continued unt dusk when the temperature had dropped to about the same level. Maximum flight activity generally was from 4 p.m. to 6 p.m. (m.d.t.), when the temperature was 23°C or higher. As table 1 shows, these observations closely agree with the work of Blackman (1931), Reid (1962a), Shepherd (1966), McCambridge (1967, 1971), and Gray and others (1972). During peak emergence the first summer, the maximum temperature reached or surpassed 32°C on two occasions. On these 2 days, beetle emergence and attacks were reduced. Gray and others (1972) found diminished numbers of emerging beetles on days when the temperature exceeded 30°C.

In each of the 3 study years, beetle emergence followed a period of relatively warm, dry weather. Reid (1962a) also found that the flight period usually began after a period of relatively high temperatures and abundant sunshine.

During the present study, many beetles observed at dusk in bark crevices and under bark scales made no attempt to bore into the trees. The following morning, no signs of beetle activity were observed until air temperature warmed to about 17°C. Then many beetles bored into the bark and others took flight. Apparently, beetles that fly late in the evening and remain concealed on the bark surface overnight become active the following morning at a temperature slightly lower than the temperature that triggers emergence and flight. The warming effect of solar radiation is probably the primary reason for this behavior (Powell 1967).

Length of flight period.--For the most part, beetles that emerged early in the flight period attacked lodgepole pines that had been strip attacked or had pitched out beetles the previous year. After a period of sparse, sporadic emergence, the bulk of the beetles emerged, flew, and made their attacks in about 1 week. In 1970, peak emergence and attacks occurred in 7 days, 9 days in 1971, and 7 days in 1972. In 1971, frequent light thunderstorms in the research area may have caused the slightly longer period of peak emergence.

Beetles emerging after peak emergence behave much the same as those that emerged early in the flight period. For the most part, they attack trees that received only a partial or strip attack. When these beetles attack previously uninfested trees, their numbers are usually insufficient and they are subsequently pitched out. In this

Table 1.--*Observer comparisons of the peak emergence and flight of mountain pine beetles*

Observer	Temperature (°C)	Time	Host	Locality
Rasmussen	23	4 p.m.-6 p.m.	Lodgepole	Utah, Idaho
Reid	22	1 p.m.-4 p.m.	Lodgepole	British Columbia
Shepherd	22	--	Lodgepole	British Columbia
Blackman	--	4 p.m.-dusk	Ponderosa	Arizona
Gray and others	20	11 a.m.-2 p.m.	Ponderosa	Washington
McCambridge	20	4 p.m.-6 a.m.	Ponderosa	Colorado

study, lodgepole pines that were not completely mass attacked within 48 hours of the initial attacks became pitchouts; most never were observed to be successfully mass attacked. McCambridge states that in ponderosa pine (*P. ponderosa* Laws.) the mass-attack period generally lasts from 4 days to about 3 weeks. In the latter case, many attacking females are killed by being pitched out (personal communication July 1973, William F. McCambridge, USDA Forest Service, Ft. Collins, Colo.). Blackman (1931) reported that most emergence of this beetle in ponderosa pine takes place within a few days.

ATTACK BEHAVIOR

Selection of entry sites.--After alighting on a lodgepole pine most *D. ponderosae* move upward, often obliquely. Apparently, searching for a suitable niche, they examine many bark scales and crevices before boring. When beetles fail to find an acceptable niche, even on attacked trees, they take flight after searching less than 30 minutes.

The mountain pine beetle avoided smooth areas, burrowing into the bark under bark scales and in bark crevices. During this 3-year study, initial attacks occurred under bark scales 61 percent of the time and in bark crevices the remaining 39 percent. Shepherd (1965) demonstrated that *D. ponderosae* attacked rough bark more often than smooth bark. Miller and Keen (1960) reported that *D. brevicomis* normally selects the corky and rough layers of outer bark, avoiding those that are smooth and thin.

Aspect of initial attacks.--Observations made the last 2 study years revealed that 36 percent of the initial *Dendroctonus* attacks on lodgepole pine occurred on the north aspect, 25 percent on the west, 21 percent on the east, and 18 percent on the south. Shepherd (1965) found significant differences in total number of attacks per square foot among aspects; north aspects received the largest number, south aspects the smallest, and east and west aspects an intermediate number. Reid (1963) also found attack density greatest on the north aspect. Powell (1967) demonstrated that north aspects of trees had lower surface temperatures than south aspects and were about 1°C cooler than air temperatures. Temperature probably accounts for differences in the number of initial attacks among aspects. At the time of beetle attack, bark surface temperatures can be quite high. According to Shepherd (1966), *D. ponderosae* reverse their phototactic reaction between 35°C and 37.5°C and become photonegative.

Height of initial attacks.--The heights of initial attacks on trees were recorded in 1971 and 1972. Data indicated that 79 percent of the initial mountain pine beetle attacks were between 4 and 6.9 feet above ground level, 93 percent between 4 and 7.9 feet, and the remaining 6 percent below 4 feet. The mean height of attack for the 2 years was 4.69 feet. After the initial attack was made, succeeding attacks generally spread from that point up, down, and around the bole. These data are similar to general trends reported by McCambridge (1967) on ponderosa pine.

Sex ratios.--In 1972, a number of trees were marked and dated at the time they were mass attacked. Later, 10 galleries per tree were excised and examined. Data recorded included: date of mass attack, time lapse from mass attack to gallery examination, presence or absence of male beetles, presence or absence of eggs, and total gallery length. Female beetles were present in every gallery examined; the possibility of some being reemerged parents was not considered.

From a curve fitted to the data (Jensen and Homeyer 1971), it was estimated that 92 percent of the females were mated within 7 days of mass attack and 100 percent within 10 days (fig. 1). This graph includes data from galleries that had eggs, but not necessarily a male parent present. The sex ratio of the parent beetles encountered is presented in table 2. The sex ratio of the attacking population was about 1:2.3 males to females, not much different from the 1:2 sex ratio Reid (1958) found in

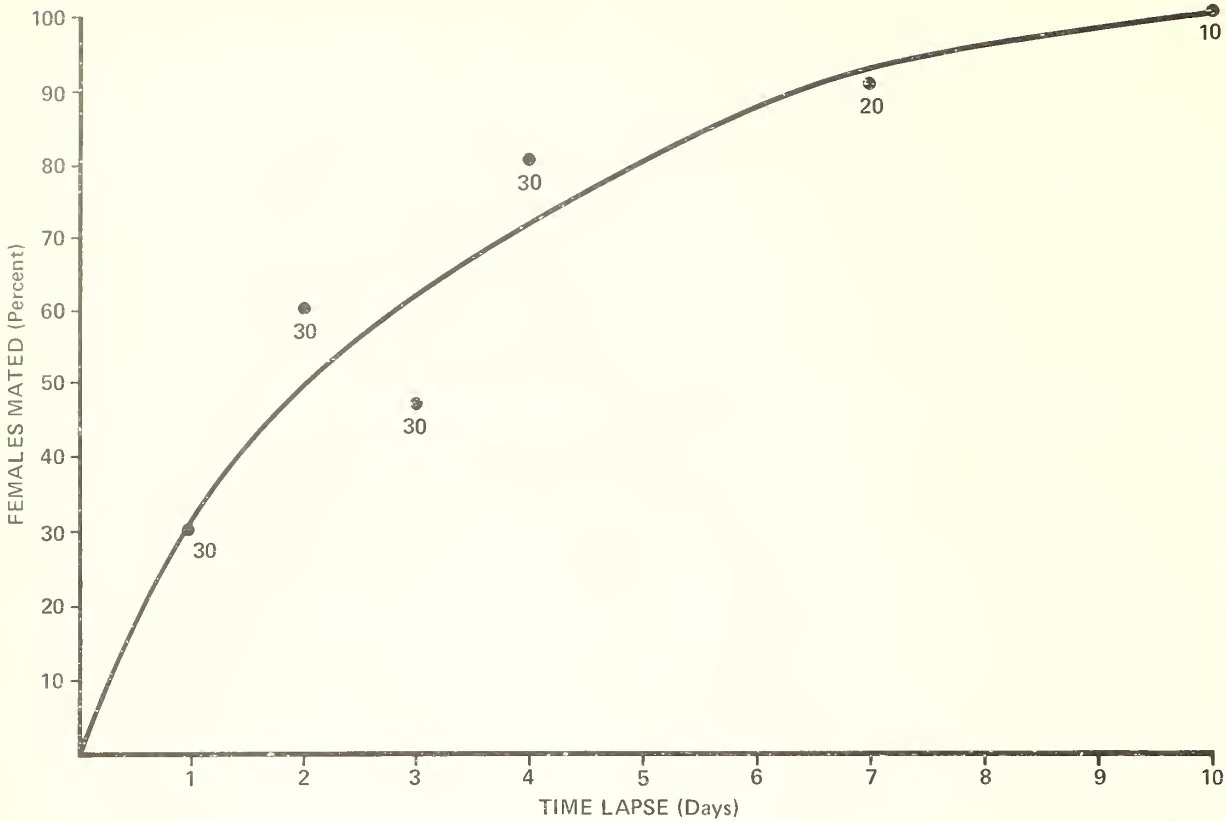

Figure 1.--Percent of females mated in relation to time elapsed from mass attack. The number of observations associated with each plotted point is indicated.

$$\hat{Y} = 100 - 1.018(10 - X)^{1.85} - 2.79 \times 10^{-10}(10 - X)^{11}$$

$$R^2 = 0.89$$

Table 2.--*Sex ratio of parent mountain pine beetles within galleries after varying lengths of time from mass attack*

Time lapse (days)	Number galleries sampled	Galleries containing		Sex ratio (all galleries)
		Both parents	Female only	♂:♀
1	30	9	21	1:3.3
2	30	18	12	1:1.7
3	30	14	16	1:2.1
4	30	13	17	1:2.3
7	20	8	12	1:2.5
10	10	4	6	1:2.5
Total	150	66	84	1:2.3

recently attacked lodgepole pine. Assuming that none of the females were mated before emergence and flight (McCambridge [1970] found that about 2 percent were mated in ponderosa pine), they were mated shortly after mass attack. The sex ratio of beetles emerging from trees attacked within the study area in 1971 was 1:2.9. Other workers (Reid 1962b; Safranyik and Jahren 1970) also found that newly emerged female mountain pine beetles outnumber males. Because the emerging population had a slightly larger proportion of females than the attacking population, females apparently have a higher flight mortality than males. However, because the male will mate with more than one female, this imbalance is not limiting.

Rate of gallery construction.--The data were analyzed to show the difference in the rate of gallery construction by mated and unmated females (fig. 2). The female was considered to be mated if a male or eggs were present. Results of a weighted covariance analysis suggest that differences in gallery length are real. Reid (1958) also found that mated females extended their galleries at a greater rate than unmated females. Unmated females may elongate their galleries at a lower rate because longer galleries are more difficult to keep free of boring residue. If the gallery were to become plugged the male would be excluded and mating could not take place.

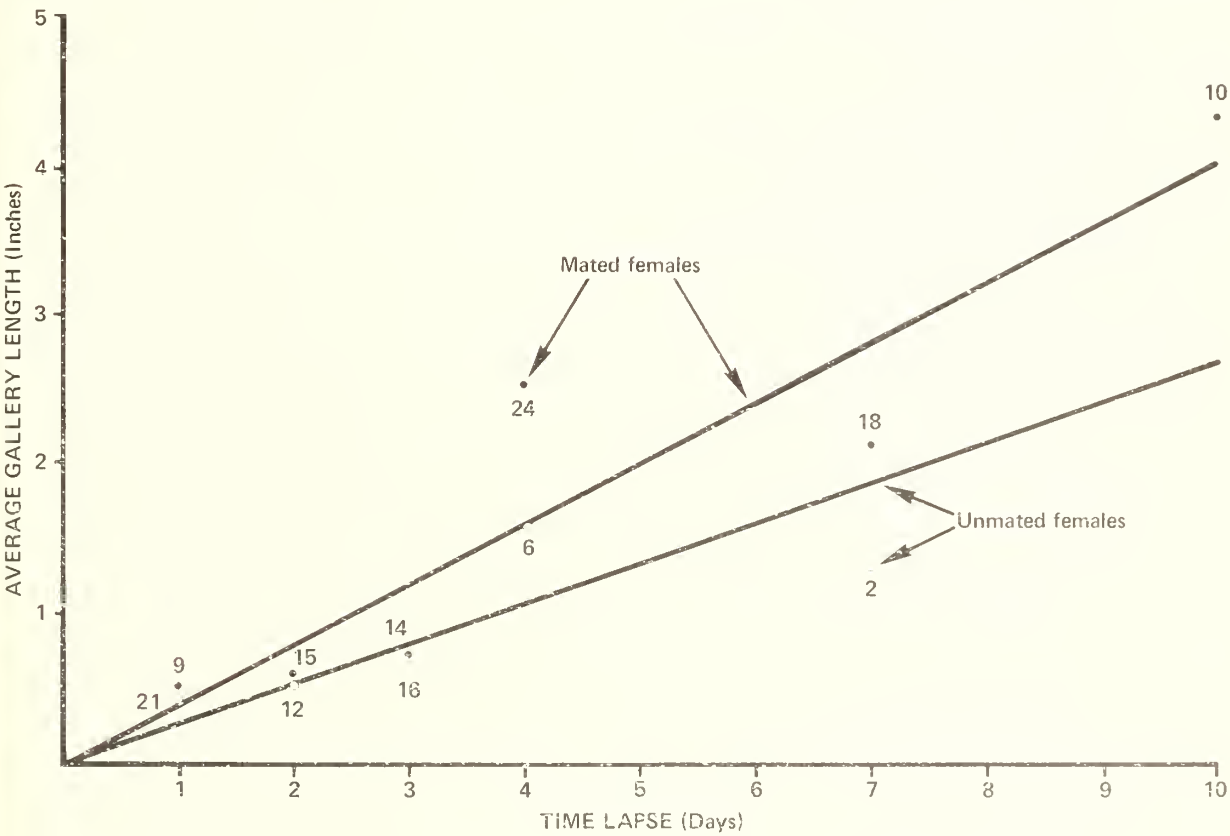

Figure 2.--Comparison of rates of gallery construction by:

Mated females, $\hat{Y} = 0.4054\ X,\ R^2 = 0.53;$

Unmated females, $\hat{Y} = 0.26856\ X,\ R^2 = 0.31.$

The number of observations associated with each plotted point is indicated.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-181

April 1974

REDUCING FIRE POTENTIAL IN LODGEPOLE PINE BY INCREASING TIMBER UTILIZATION

James K. Brown[1/]

ABSTRACT

Fuel and fire potential in clearcut lodgepole pine were compared after stands were logged to near complete and conventional utilization standards. After logging, material greater than 3 inches in diameter had been reduced threefold on the near complete units and had been increased threefold on the conventional units. Material smaller than 3 inches in diameter was slightly less plentiful on the near complete units than on the conventional units after logging; however, of this material, the conventional units retained 2.6 times more needles. Compactness of logging residue was twice as great on the near complete units as on the conventional units. Predictions of postlogging potential fire spread were 3 to 4.5 times greater and intensity almost 9 times greater on the conventional than on the near complete units. Fire hazard on the near complete units after logging was minimal and prescribed burning was impractical.

OXFORD: 431.2
KEYWORDS: fuel, fire hazard utilization, lodgepole pine

Land managers have long known that fuels and fire potential on logged areas can be reduced through increased utilization of residues; the question is, "Exactly how much does increased utilization reduce the fire hazard, compared to conventional utilization?" Some answers were obtained for lodgepole pine (*Pinus contorta* Dougl.) clearcuttings in Wyoming.

[1/]Research Forester, stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

STUDY PROCEDURES

Two even-aged lodgepole pine stands near Union Pass on the Teton National Forest in Wyoming were selected for the study. The stands had an average site index (50-year base) of 40 and averaged 167 and 182 years of age.

Two 20-acre harvesting units were laid out in each stand. One unit was clearcut to "conventional" standards, the other to standards that for this study were called "near complete." On both the conventional and near complete harvesting units all sound trees to a merchantable top diameter of 6 inches were removed. In addition, on the near complete units chips were produced from (1) tops of all merchantable trees, (2) all remaining live and dead sound standing trees with a d.b.h. of 3 inches or larger, and (3) all sound dead material remaining on the ground that was more than 6 inches in diameter at the larger end and that was more than 6 feet long. On the conventional units, trees were limbed and bucked where felled, and skidded by crawler tractor to the landing. On the near complete units, trees were felled, and then bunched and skidded to a central point where the sawlog material was removed. The remaining top material was then skidded to the chipper.

Volumes of live and dead standing trees to a 6-inch top ranged from 6,250 to 8,180 ft^3 per acre for the four harvesting units. Effects of the different harvesting treatments on the yield of fiber are described in a paper by Gardner and Hann.[2/]

To assess the effects of the two utilization standards on fuel characteristics, fuels were inventoried before and after logging. Sampling was done using a grid. At each sample point, fuel loading (weight per unit area) by size class, fuel depth, duff depth, and percent ground cover were measured. The branchwood size classes were 0 to 0.20 inch, 0.21 to 0.60 inch, 0.61 to 3.0 inches, and over 3.0 inches. The first three classes correspond to the 1-, 10-, and 100-hour moisture timelag classes used in the National Fire-Danger Rating System.[3/] Bulk density of the duff was determined from ten 1-ft^2 samples systematically taken in each stand.

Fuel loading for downed dead branchwood was determined using the planar intersect technique.[4/] For material less than 3 inches in diameter, a 5-foot line transect was located at each grid point. The numbers of branchwood particles intersecting the vertical plane projected by the 5-foot line were tallied by the first three size classes.

Loading for each size class was computed from

$$w = \frac{\rho \pi^2 d^2 n}{8L} \qquad (1)$$

where

w = loading, lb/ft^2
ρ = particle density, lb/ft^3
d = root mean square for diameter of fuel particles, ft
n = number of intersections per sample line
L = length of sample line transect, ft.

2/ R. B. Gardner and D. W. Hann. Utilization of lodgepole pine logging residues in Wyoming increases fiber yield. USDA For. Serv. Res. Note INT-160, 6 p. 1972.

3/ J. E. Deeming, J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder. National Fire-Danger Rating System. USDA For. Serv. Res. Pap. RM-84, 165 p. 1972.

4/ J. K. Brown. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96-102. 1971.

The number of intersections for equation (1) was determined from the field inventory and the following values[5] used for the other two variables in equation 1:

Size class (*Inches*)	*d* (*Feet*)	ρ (Lb/ft^3)
0.0 - 0.2	0.0082	35
.2 - .6	.0279	35
.6 - 3.0	.1180	30

The number of needle-bearing branches less than 0.6 inch in diameter was tallied along each 5-foot sample line. Using these data, the loading of needles attached to branches was computed from

$$w_n = RF(w_1 + w_2)^{6/} \tag{2}$$

where

w_n = needle loading, lb/ft^2
R = ratio of needle weight-to-stem weight
F = fraction of twigs bearing needles
w_1 = loading for 0 - 0.2 size class, lb/ft^2
w_2 = loading for 0.2 - 0.6 size class, lb/ft^2.

Loading of material greater than 3 inches in diameter was determined by recording the diameter of each piece intersecting a 50-foot line transect. For a particle density of 25 lb/ft^3, equation 1 then becomes

$$w = 0.6168\ \Sigma d^2 \tag{3}$$

where

d = diameters of intersected pieces, ft
w = loading, lb/ft^2.

Fuel depth was systematically sampled using three measurements at each grid point. Depth was measured as the vertical distance from the ground to the highest dead fuel particle intersecting a cylinder whose central axis is the vertical projection from a point on the ground and whose radius is 5 cm. Maximum depth attainable was 6 feet.

Duff (F and H layers of forest floor) depth was measured twice at each grid point. Percent of the ground covered by mineral soil, forest floor litter, woody material (including branches and tree boles), grass and forbs, and brush were ocularly estimated on a 1/300-acre plot at each grid point.

Percent errors (100 X standard error of the mean ÷ estimated value) averaged 18 percent for each size class of branchwood, 17 percent for fuel depth, and 11 percent for duff depth, on each individual harvesting unit.

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[5] Values based on unpublished data on file at the USDA Forest Service, Northern Forest Fire Laboratory, Drawer G, Missoula, Montana.

[6] R = 0.9 and is a ratio adjusted for this study from data in: J. K. Brown. Vertical distribution of fuel in spruce-fir logging slash. USDA For. Serv. Res. Pap. INT-81, 9 p. 1970. F is necessary for current application of R and was determined from the field inventory.

RESULTS AND DISCUSSION

The main differences in the two harvesting treatments were in the amount of material over 3 inches and fuel depth after logging (table 1). On the near complete units, loading of material over 3 inches was reduced to one-third of the prelogging amount. On the conventional units, loading increased by a factor of 3. Although this size contributes little to the spreading flame front of a fire, it does contribute measurably to total fire intensity. It also contributes indirectly to fire spread by helping support smaller sized fuel at a more flammable level of compactness.

Fuel depth was lowered by both harvesting methods, primarily by removing grouse whortleberry (*Vaccinium scoparium*). However, change in fuel depth is not as important as the depth and packing ratio of fuel after logging. (The packing ratio is the ratio of fuel volume to the volume of the fuel bed.) The packing ratio for material less than 3 inches averaged 0.062 on the near complete units and 0.030 on the conventional units. The optimum packing ratio for combustion for this study using Rothermel's[7]

Table 1.--*Ground fuels averaged for near complete and conventional utilization standards before and after logging*

Fuel item	Near complete			Conventional		
	Before	After	Change	Before	After	Change
Loading	- - - - - - - - - - - - Tons/acre - - - - - - - - - - - -					
Needles	0	0.40	0.40	0	1.05	1.05
Branchwood (inch)						
0 - 0.2	.14	.10	-.04	.20	.15	-.05
0.2 - 0.6	.82	1.32	.50	.96	1.92	.96
0.6 - 3.0	3.38	8.64	5.26	4.22	9.70	5.48
Total	4.34	10.46	6.12	5.38	12.82	7.44
Over 3.0	27.0	9.0	-18.0	16.5	44.0	27.5
Ground Cover	- - - - - - - - - - - - Percent - - - - - - - - - - - -					
Mineral soil	2	42		1	29	
Forest floor litter	48	26		51	40	
Wood	21	31		19	29	
Grass	22	0		13	1	
Brush	2	0		16	1	
	- - - - - - - - - - - - Inches - - - - - - - - - - - -					
Fuel Depth	10.8	3.0		13.7	7.4	
Duff Depth	.92	--		.92	--	

[7] R. C. Rothermel. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p., illus. 1972.

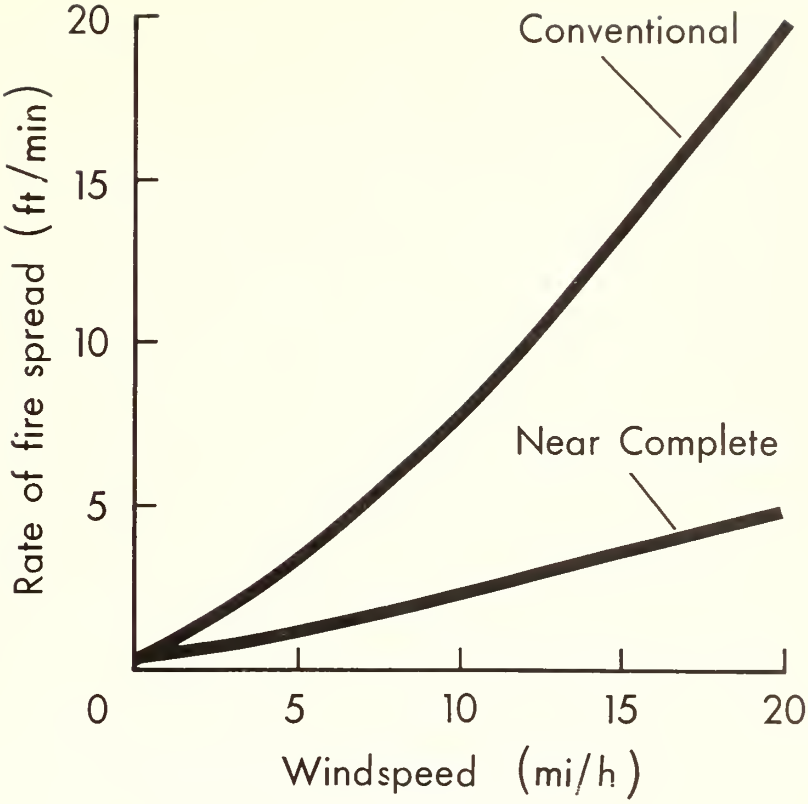

Figure 1.--Predicted rate of fire spread for fuels left after logging to conventional and near complete utilization standards.

model of fire spread was 0.009. Thus, fuel on the near complete units was compacted an average of twice as much as on the conventional units, resulting in a packing ratio that restricts combustion to a greater degree than on the conventional units.

Logging under conventional utilization standards produced only slightly more material less than 3 inches in diameter than did logging under the near complete standards. On the conventionally logged units, however, a substantially greater percentage of this material was highly flammable needles than on the near complete units. Even on the near complete units, much of the branchwood from harvested trees remained on the site, apparently broken off during the bunching and skidding of whole trees. A higher proportion of dead limbs was broken off than live limbs. The decrease in material 0 to 0.2 inch in diameter occurring after logging on all conventional and near complete units probably resulted from small twigs being crushed and churned into the forest floor by logging equipment.

Disruption of fuel continuity and exposure of mineral soil were greater on the near complete units than on the conventional units.

Forest floor duff, which averaged almost 1 inch on all units, had an average bulk density of 8.7, ±1.9 lb/ft^3. Logging methods did not reduce the amount of duff but did change its distribution.

Fire spread and intensity for the propagating flame front of a fire (this excludes spotting of firebrands) were estimated using the inventoried fuel data as inputs for a mathematical model of fire spread.[8] The predictions showed that rate of spread after logging would be about 3 to 4.5 times greater on the conventional blocks (fig. 1).

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[8] Ibid.

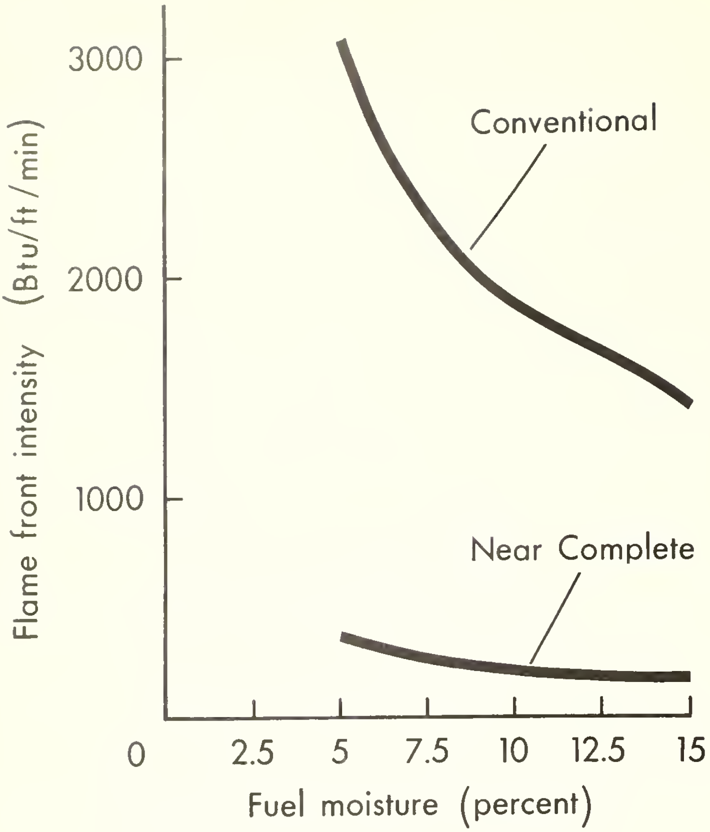

Figure 2.--Predicted intensity for a flame front for fuels left after logging to conventional and near complete utilization standards.

Intensity of the flame front (Btu/ft/min - heat from a 1-foot-wide cross section through the propagating flame front) would be 8.8 times greater on the conventional blocks for any fuel moisture (fig. 2). Intensity would vary from that figure somewhat for different wind conditions. The estimate of intensity on the conventional units is conservative because material greater than 3 inches in diameter was not included in the mathematical model. Further, the packing ratio used in the prediction model was higher than for the slash itself because many depth measurements had been taken on areas where no slash existed. This also resulted in lower than expected intensity values on the conventional units.

CONCLUSIONS AND IMPLICATIONS

Logging to near complete utilization standards reduced fire potential to a point that no further fuel modification should be required for hazard reduction. In fact, not enough fuel remained for prescribed burning, a treatment that might be required to meet silvicultural objectives.

Logging to conventional utilization standards left the fire potential high enough to warrant fuel modification for hazard reduction. Without fuel modification, direct attack on a fire would not be possible under many burning conditions.

On this lodgepole pine study site, and probably in many other timber stands, complete utilization eliminates unreasonable fire hazards. The desirability of complete utilization, however, must also consider the need for residue material to carry prescribed fire, stabilize soils, shade seedlings, and recycle nutrients. The wisdom of complete utilization should be evaluated by considering the land management goals for each individual site.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-182 July 1974

SNOW CACHE TEMPERATURES SUITABLE FOR STORAGE OF CONIFER NURSERY STOCK

Russell A. Ryker, Allen K. Dahlgreen,
Frank E. Morby, and David L. Johnson [1]

ABSTRACT

Snow caches provide good temperature control for conifer nursery stock, which generally requires that storage temperatures be just above freezing and maintained with minimum fluctuation. Temperatures amid boxed trees were measured within a pit snow cache, a culvert snow cache, and a refrigerated cooler. Temperatures were lowest in the pit snow cache and highest in the nursery cooler. Temperature fluctuations within boxes were much more pronounced in the nursery cooler than in either snow cache. Also determined were prevailing temperatures within three kinds of tree packages stored in the pit snow cache.

For many years, National Forest personnel in the Intermountain Region have stored nursery stock in snowbanks. Packaged trees are placed in caches soon after being lifted from nursery beds in early spring (late February to early April) and are kept there until stock is planted (early April to mid-July, depending on location). When such caches have been properly prepared, vigor of stored trees has been successfully maintained. However, when large snow caches are needed, heavy equipment is required to construct the cache and to open snow-clogged roads in early spring. This is a costly operation in remote areas.

To avoid some costs, Payette National Forest personnel transported trees on oversnow machines and stored them in pipe culverts (5 feet in diameter and 20 feet in length) that had been placed close to the planting site the previous fall. In this way, trees can be stored near remote planting areas without entailing the use of heavy equipment or large crews. Results of a small test the spring of 1970 were encouraging. An expanded culvert storage of 800,000 trees in 1971 also was successful.

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[1]Respectively, Silviculturist, Intermountain Station, Boise, Idaho; Silviculturist, Regional Office, Intermountain Region, Ogden, Utah; Nurseryman, Lucky Peak Nursery, Boise, Idaho; and Silviculturist, Regional Office, Alaska Region, Juneau, Alaska.

Some people consider snow storage to be a primitive and costly procedure, and believe that refrigerated storage facilities should be expanded at nurseries or built at central locations. Certain stock-handling advantages result from artificial refrigeration, but the risks of mishandling are increased during a long trip to the planting site in hot weather.

Before costly improvements in transportation and storage facilities are made, the storage environment needed to keep trees in condition for good survival and growth after planting must be determined. For instance, little is known about the environment within properly prepared snow storage facilities compared to that of refrigerated storage facilities. As a step toward acquiring such knowledge, a study of temperatures in three different storage facilities was conducted in Idaho during the spring of 1972.

OBJECTIVE

The primary study objective was to determine temperature regimes near root mass centers in packages of tree seedlings stored in (1) a conventional pit snow cache, (2) a preplaced culvert pipe snow cache, and (3) a storage cooler at the Lucky Peak Nursery near Boise, Idaho.

A second objective was to determine temperatures prevailing within three different kinds of tree packages in a pit snow cache.

METHODS

Ponderosa pine (*Pinus ponderosa* Laws.) was used in all storage comparisons. All trees were lifted, sorted, packaged, and stored at the nursery by March 31, 1972. Trees to be stored in the snow were delivered April 12 by refrigerated truck to cache locations on the Payette National Forest administrative site, McCall, Idaho. McCall, which has an altitude of 5,025 feet, recorded 171 inches of snowfall from Sept. 29, 1971, to April 12, 1972. Trees for refrigerated storage were kept at the Lucky Peak Nursery.

Comparison between storage facilities was made with trees packaged in 2-mil-thick polyethylene bags, which were placed inside cardboard boxes. In the pit snow cache, we monitored temperatures in three kinds of packages: (1) wooden tree crates; (2) polyethylene-lined bags (1/2-mil-thick polyethylene coating on inner surface of 3-ply paper bag); and (3) 2-mil-thick polyethylene bags inside cardboard boxes.

Tree packages were stacked in arrangements ordinarily used by Payette Forest and Lucky Peak Nursery personnel.

Pit snow cache.--This cache comprised three rows of five stacks each. Stacks were spaced about 1 foot apart and rows 2 feet apart. Boxes were stored in the first row, bags in the second, and crates in the third. Each stack of boxes was one box wide and three boxes high; 2 by 4's were placed on edge between each tier. A stack of bags consisted of four bags; the two lower bags were separated from the two upper ones by about 1 foot of snow and some boards across the trench. A stack of crates was also four high, but 2 by 4's placed on edge separated the two top crates in each stack.

A chromel alumel thermocouple was placed near the center of the root mass in each type of package. An instrument was placed in each of the three boxes in stacks 1, 3, and 5; in the bottom and third bags in stacks 1, 3, and 5; and in each of the four crates in stacks 1, 3, and 5 (fig. 1). Thermocouple leads were long enough to reach outside the cache after it was closed; consequently, all temperature readings were obtained without disturbing the cache.

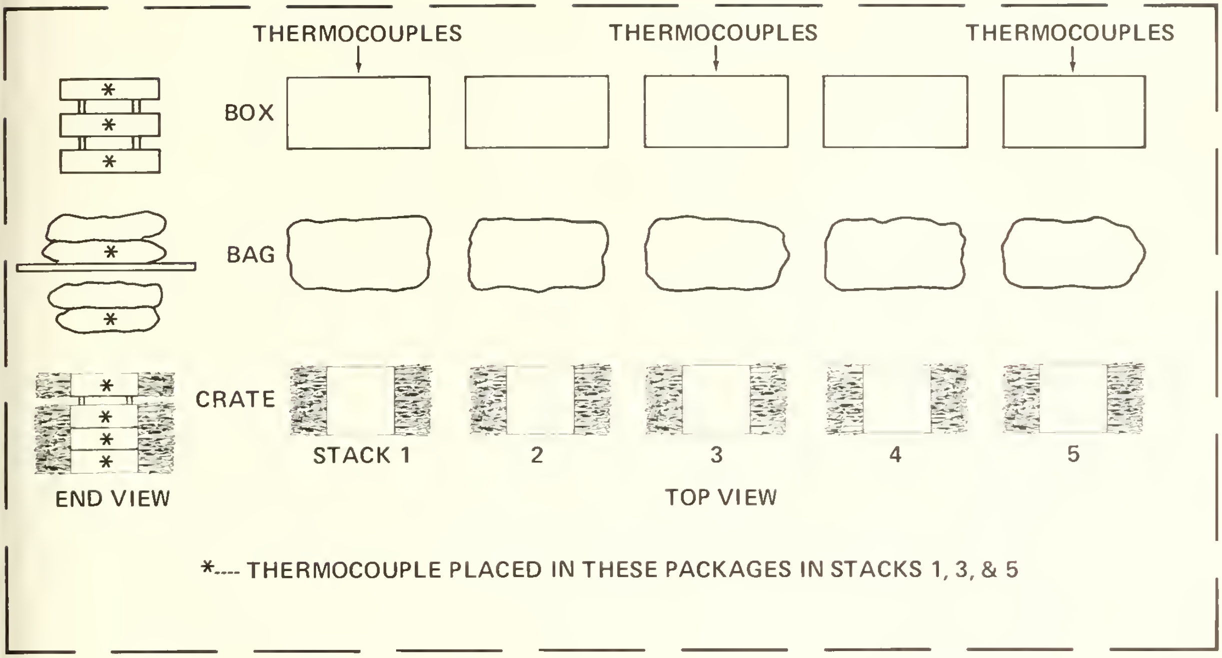

Figure 1.--Arrangement of boxes, bags, and crates within the pit snow cache.

Snow was shoveled between all the packages, and then an end loader was used to cover the cache in depth. The storage area was then insulated to deter melting.

Culvert snow cache.--During the winter, the pipe was buried under several feet of snow that slipped from the north side of a warehouse roof. An entry was dug, and the pipe was then filled with five stacks of boxes. A stack was three boxes wide and three boxes high. Thermocouples were placed in stacks 1, 3, and 5; only the four corner boxes in each of these stacks were not instrumented (fig. 2). Thermocouples also measured air temperature between boxes and pipe at the top, the bottom, and on both sides of stacks 1, 3, and 5. Leads were run to the outside, and the cache entry was closed with snow.

Nursery cooler.--Boxes of trees were stacked on one pallet for storage in the nursery cooler. The stack had four tiers of four boxes each. A thermocouple was placed in the middle box of each tier (fig. 3). A thermocouple was used to measure ambient air temperature also.

Other duties and equipment difficulties prevented us from taking regular measurements until the 12th day of storage at McCall and the 15th day of storage at Lucky Peak. Thereafter, thermocouples were read 3 days a week at McCall and daily, except for weekends, at Lucky Peak. Measurements stopped when trees were first taken from the caches or were shipped from the nursery. Outside air temperatures during the storage period were obtained from established weather stations at Lucky Peak and McCall.

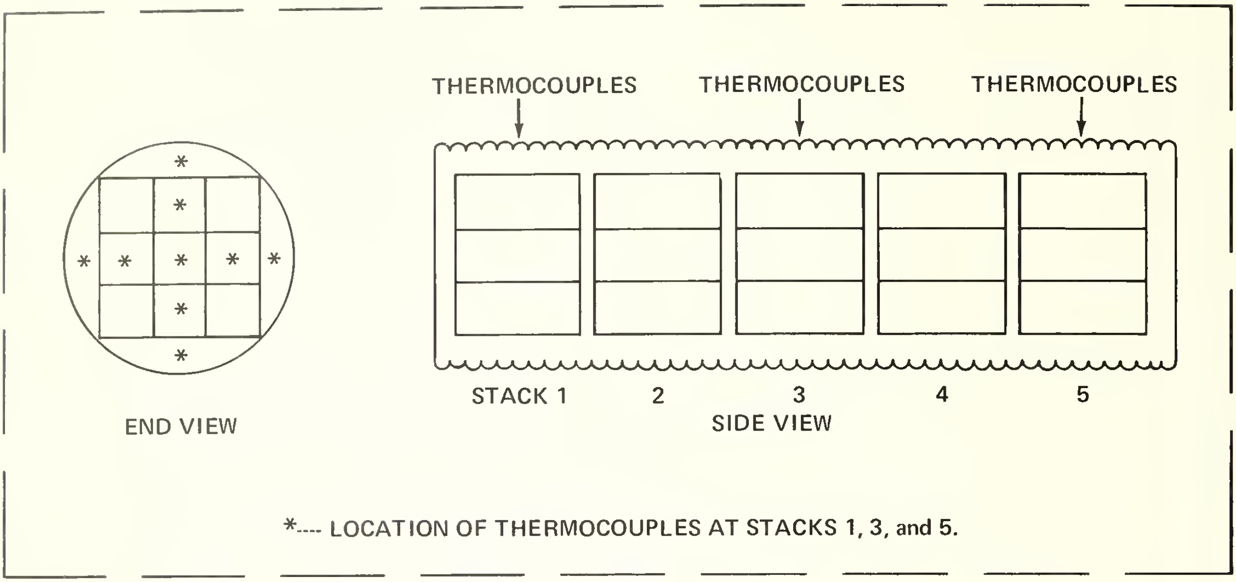

Figure 2.--Arrangement of boxes and thermocouples within the culvert snow cache.

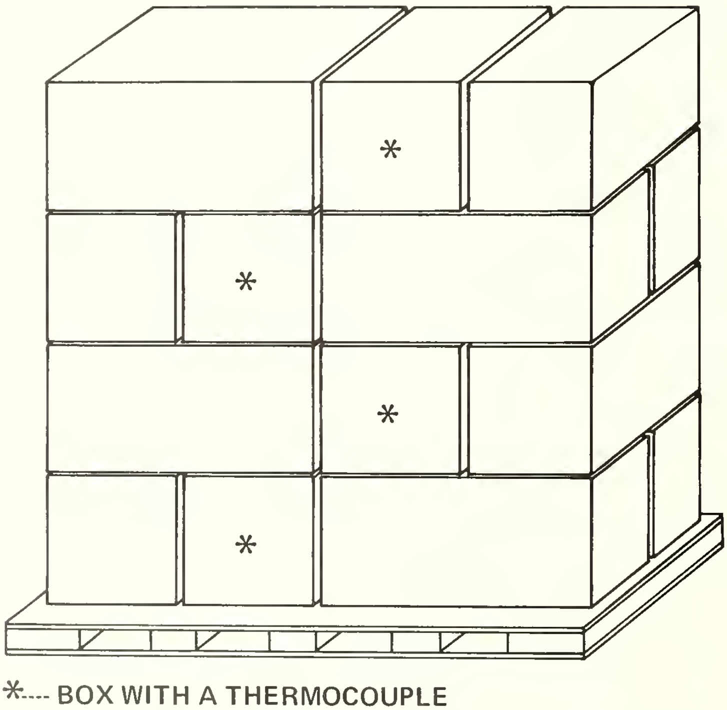

Figure 3.--Arrangement of the 16 boxes stacked on a pallet in a nursery cooler. A thermocouple was placed in the middle box of each tier.

RESULTS

Comparison of Storage Facilities

Mean temperatures amid boxed trees were generally lowest in the pit snow cache and highest in the nursery cooler (fig. 4). Temperatures amid culvert-stored trees were intermediate, averaging about 1 degree warmer than those in the pit snow cache.

Temperatures within boxes fluctuated more in the nursery cooler than in the snow caches (fig. 4). The following tabulation indicates the range of individual temperature measurements and their means for the storage period.

Storage	*Number of thermocouples*	*Temperature (°F)* Range	Mean	Mean ambient
Pit snow cache	9	32-36	34	32
Culvert snow cache	15	33-37	35	33
Nursery cooler	4	34-42	38	37

The temperature deviations in the nursery cooler appeared to be influenced strongly by outside temperatures (fig. 5), an indication that refrigeration equipment was inadequate or responded too slowly to outside changes. Equipment modifications have been made to insure more constant temperatures.

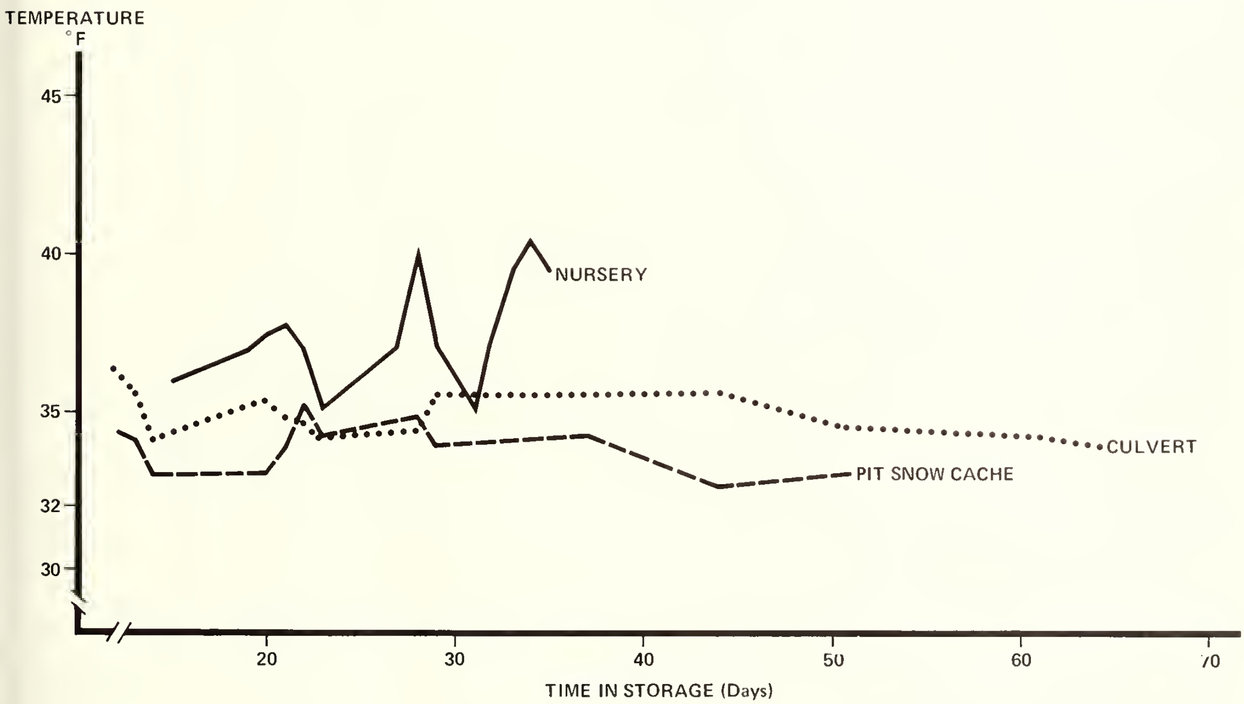

Figure 4.--Mean temperatures of boxed trees were lower in the snow caches than in the nursery cooler. Curves stop when the first study trees were removed from the caches or from the nursery.

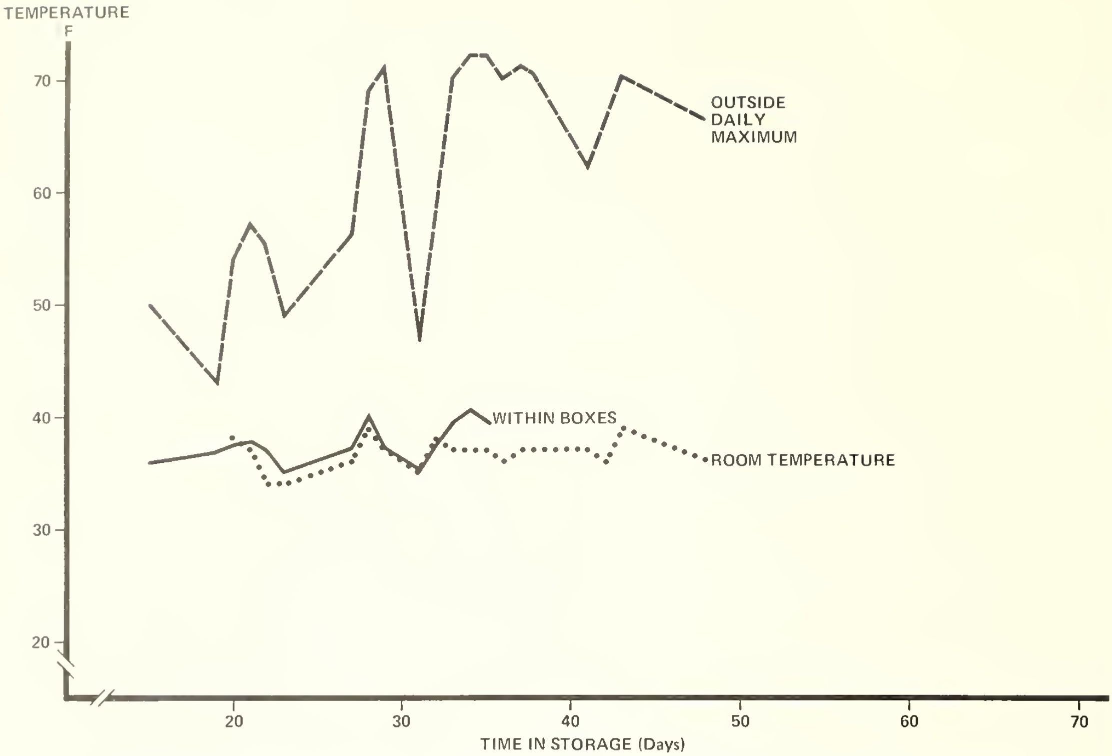

Figure 5.--Fluctuations in mean temperatures amid boxed trees and in room temperatures apparently were influenced by daily maximum temperatures of the outside air.

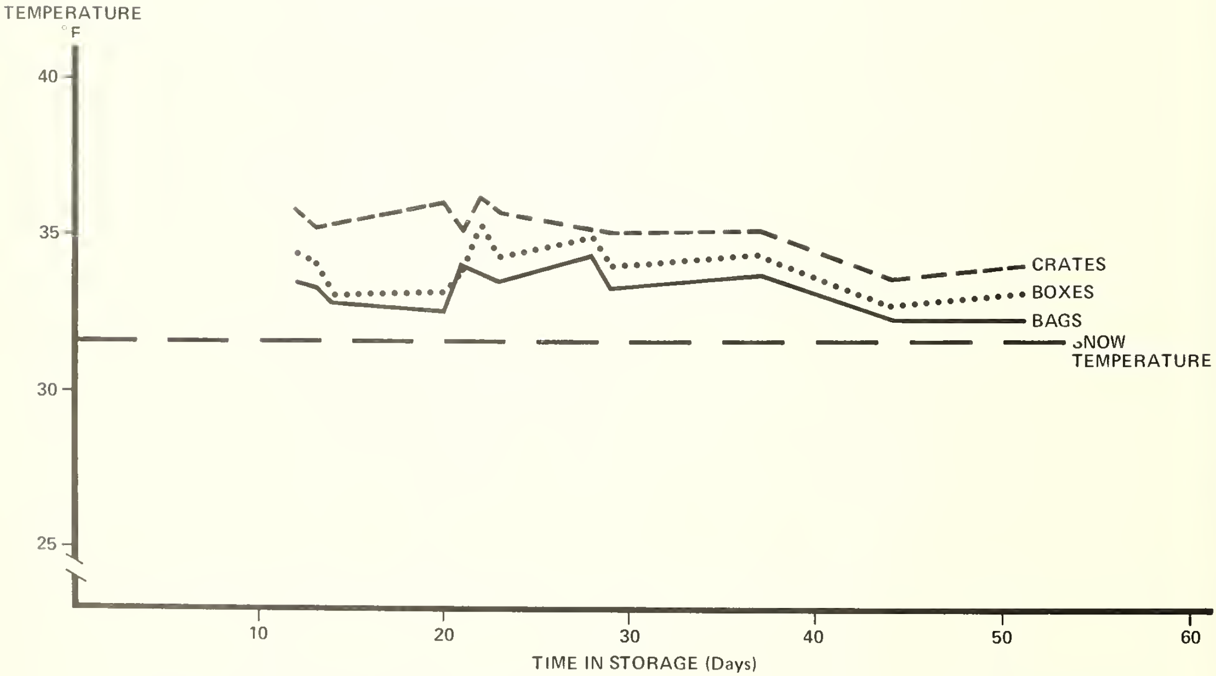

Figure 6.--In the pit snow cache, mean temperatures amid the roots were highest for crated trees and lowest for bagged trees.

Comparison of Packages

In the pit snow cache, mean temperature in crates (35°F) was higher than that in boxes (34°F), which, in turn, was higher than that in bags (33°F). These differences prevailed throughout much of the storage period (fig. 6). Arrangement within a stack appeared to have little effect on temperatures within the container (table 1).

Table 1.--*Mean temperatures within tree packages by position within a stack, pit snow cache*

Position	Temperature (°F)		
	Crate	Box	Bag
Top tier	35	--	--
Second tier	36	34	33
Third tier	35	34	--
Bottom tier	35	34	33

DISCUSSION AND CONCLUSIONS

This study demonstrates that satisfactory storage temperatures can be maintained in snow caches. Lower and more uniform temperatures were maintained amid packaged trees in both snow caches than under existing conditions in the nursery cooler. Satisfactory storage conditions can be provided by artificial refrigeration, but equipment must be adequate to maintain uniformly low temperatures. Admittedly, the effects of different storage environments on survival and growth of outplanted trees should be studied thoroughly, but our data show that properly prepared snow storages can provide good conditions for holding trees until planting time.

Though temperatures inside crates of trees were only 1 to 2 degrees warmer than temperatures in bags of trees, this difference might affect survival and growth in some species. At temperatures around freezing, small changes in temperature have relatively large effects on respiration and depletion of food reserves--and conceivably could affect survival, especially after long storage periods.

Research is needed to determine more precisely the best packaging and storage regime for each species. Preliminary results of a study of trees stored in the Lucky Peak Nursery cooler indicate that some species survive and grow better after storage in crates, whereas others do better after storage in boxes and bags. Similar studies of trees held in snow caches are needed.

Successful storage of nursery stock in snow depends on proper location, installation, and maintenance of the caches. Many observed failures of snow caches in the Intermountain Region were attributable to improper location and preparation. A companion article is being prepared that will explain how to locate sites for and install snow caches.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1973 — 784-494 / 63 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-183

August 1974

CONIFER THINNING GUIDES IN FIVE STEPS

Dale O. Hall[1]

ABSTRACT

Estimates for five elements, (a) the ring-per-inch growth rate potential, (b) the site index-basal area standard, (c) a size-merchantability limit forecast, (d) a proposed reentry period or cutting cycle, and (e) the minimum operable volume per acre, are used to suggest stems-per-acre and spacing standards for thinning operations. Ponderosa pine data are used to illustrate the thinning guides.

OXFORD: 242; 232.43; 535.
KEYWORDS: thinning, spacing, stocking, plantation management, ponderosa pine.

Historically, foresters have lacked methods to make accurate predictions about stand response to thinning. Many thinned stands have failed to reach anticipated diameter growth levels because not enough trees were removed. We have failed to appreciate fully tree growth response potentials or have overestimated mortality rates. Improved systems are needed for estimating spacing-stocking-growth relations to insure a fuller recognition of tree growth potentials.

The time it takes to produce merchantable material in timber stands is critical from an investment viewpoint. This stress on time applies to both Government and industrial land managers. For example, the Forest Service Manual (2415.21, 1972) directs that "...rotations should be the minimum periods which will ensure reaching the timber size and quality objectives...." Thinning overstocked stands is imperative if time objectives are to be attained.

THINNING OBJECTIVES

Assuming no significant change in timber quality due to different stocking levels, an ideal schedule for thinning even-aged stands would have the general objective of producing merchantable size trees as rapidly as possible. Reaching the objective would require the forest manager to:

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[1]Principal silviculturist, stationed in Boise, Idaho.

1. Thin within a few years (perhaps 1 to 3) of the onset of inter-tree competition.

2. Thin precommercially twice. The first thinning would reduce initial stems per acre, not to the stocking level desired at first commercial thinning but to about 1-1/2 times this level. The surplus trees are needed to offset mortality, judgment errors as to form and release capacity, and utilization changes which reduce the merchantable size limit, i.e., increase the stems per acre stocking level objective. The excess trees may also provide shade to restrict limb and ground cover development, and generally ameliorate environmental stresses caused by the release cutting.

   The second thinning (after 3 to 5 years) is to select final crop trees and space them for fastest growth. Some managers may elect to combine these two thinnings into one.

3. Thin commercially the first time when a desirable percentage (perhaps 80 percent) of the stand has attained merchantable size.

4. Thin commercially as frequently as growth provides volumes sufficient to warrant harvesting operations without reducing the number of stems below the prescribed final harvest stocking level.

The onset of inter-tree competition has been one of the most difficult points to determine, yet this condition is the key to minimizing the time to reach the rotation size objective and to schedule thinning operations.

THE FIVE-STEP METHOD

If we know, or can estimate: (1) site diameter-growth potentials; (2) the basal area stocking level where inter-tree competition begins; (3) how much volume per acre is necessary to log profitably; (4) the cutting cycle; and (5) future tree size objectives, then thinned spacing and stocking levels may be calculated or shown graphically. The principles of the five-step method have general application when setting thinning standards. The approach differs from earlier ones (Gaines and Kotok 1954; Myers 1967) in that the upper limit of stocking (in basal area) is prescribed, while the level after thinning varies with size and time until the stand is reentered. This method is only intended for use until specific site data, such as from the western regional levels of growing stock studies for ponderosa pine and Douglas-fir (Myers 1967; Schubert 1971; Williamson and Staebler 1965, 1971; Bell and Berg 1972) are available.

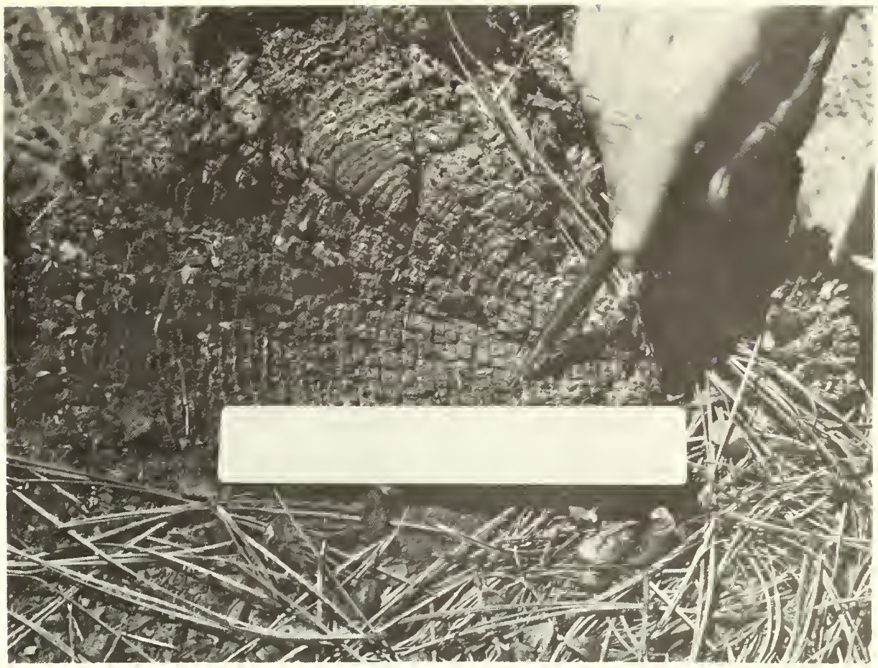
Five factors need values in order to apply the five-step method to a particular site: (1) the ring per inch (RPI) growth rate potential; (2) the site index-basal area standard; (3) a size-merchantability limit forecast; (4) a proposed reentry period, or cutting cycle; and (5) the minimum operable volume per acre. Specific data for ponderosa pine are used to illustrate application of the method for one species.

Step 1.--Determining Growth Rate Potential

The growth rate potential in rings per inch (RPI) can be determined in several ways. Old stumps can provide good estimates of a site's breast height RPI potential (fig. 1). The fastest growth rates observed will indicate periods of least competition. A random sampling of stumps over the proposed thinning area can quickly suggest what growth rate to expect.

Increment cores from young trees or cross-sections from saplings, grown for some time without competition, also provide good working estimates.

Figure 1.--Stump which suggests a 6-ring-per-inch site growth potential.



As a last resort, and only when direct observations fail to satisfy the stand manager, site index measurements may be used. The following tabulation gives preliminary RPI growth rate potentials for ponderosa pine site index classes (Meyer 1938). The values are based on limited field observations, and should be considered tentative until revised and refined by more extensive studies.

Site index class		*RPI*
Base age 100	*Base age 50*	
30-70	17-43	10-6
70-110	43-73	6-4
110-130	73-89	4-3
130-150	89-105	3-2
150+	105+	2 or less

Naturally, the tree vigor at time of thinning will dictate how long the tree requires to reach the RPI potential. Crown length and vigor classes could add some refinement in estimating this factor. For simplification, these refinements are not considered in this general presentation of the method.

Thinning of large areas is desirable to insure economical future harvest offerings. Large areas imply a range in site conditions. To assure a uniform stand size at a proposed harvest date, different thinning standards may be necessary in parts of a large area. Area maps and records should show site index and RPI growth data to balance thinning needs over cutting units.

Step 2.--Developing Basal Area Stocking Standards

Basal area per acre stocking standards must be developed for each species and site combination. Experience has shown many thinnings to be overly conservative. Growth rates have increased after thinning, but spacing was generally too close to permit trees to respond fully.

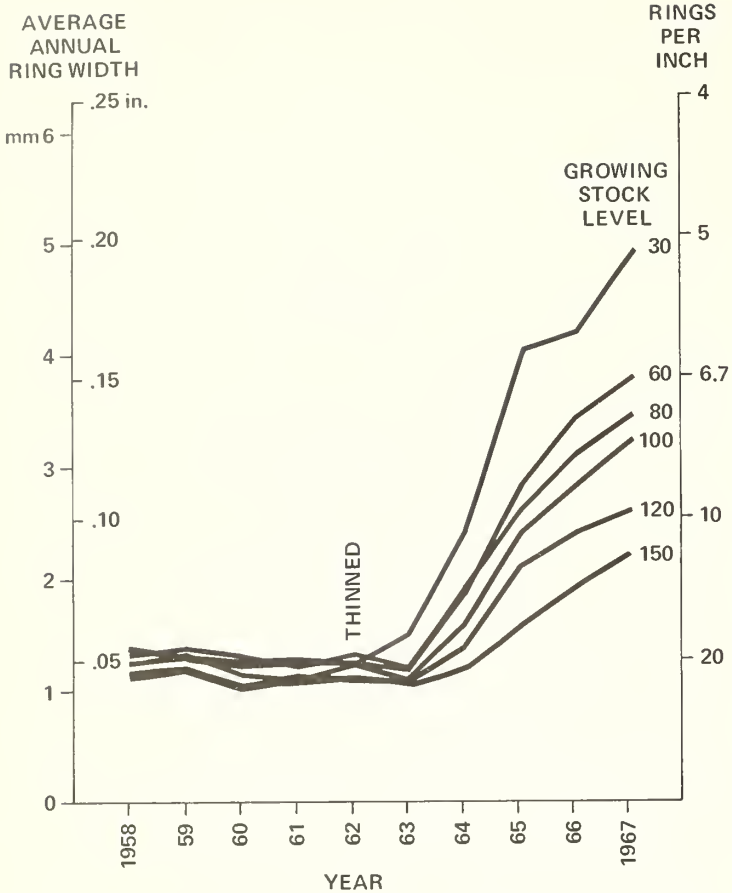


Figure 2.--Comparison of annual ring width of young ponderosa pine before and after thinning to different growing stock levels in the Taylor Woods plot on the Fort Valley Experimental Forest, Site Index 88 (Minor 1964). (Adapted from Schubert 1971).

Schubert (1971) shows that on ponderosa pine site index 88_{100} (base age 100) (Minor 1964; comparable to Meyer 1938, 68_{100}) competition is starting when stands attain 40 to 45 ft^2 of basal area (fig. 2). Stands thinned in 1962 to about 19 ft^2 basal area (growing stock level 30; Myers 1967) showed growth rates increased from 20 to 5 rings per inch in 1967. Rates were still short of the maximum growth rate the site could support when basal area was 30 ft^2. At growing stock level 60, growth was slowing in 1967 when basal area was 46 ft^2.

On the Spokane Indian Reservation (USDI, Bureau of Indian Affairs 1972), where the ponderosa pine site index averages about 90_{100} (Meyer 1938; comparable to Minor 1964, 99_{100}) when average all-age sawtimber basal area approaches 45 ft^2 the gross annual growth is predicted to be 275 board feet (Scribner) per acre. This is 94 percent of the mean annual increment according to normal yield tables for even-aged stands (Meyer 1938). Differences in production between even-aged and all-aged systems are assumed to be insignificant (Baker 1934, p. 209).

These two studies suggest that 45 to 55 ft^2 may be reasonable basal area stocking standards for Meyer's site index $70\text{-}110_{100}$. Basal area is increasing about 4 ft^2 per year at this stocking level so that a later change in stocking standard, for instance, from 55 to 64 ft^2 represents just 3 more years of growth. At rates of 5 rings per inch, the growing stock level 30 stand at Fort Valley will reach 45 ft^2 of basal area by 1974. Growth from 19 to 45 ft^2 of basal area in 12 years illustrates the stand growth potentials and suggests that heavy thinning will be necessary to sustain high growth rates on individual trees.

Interim ponderosa pine basal area stocking standards for the onset of competition related to site index (Meyer 1938) are:

Site index$_{100}$	*Basal area*
	ft^2
70	45
90	50
110	55

Step 3.--Estimating Economic Size and Merchantability Limits

A stand manager must try to predict what the minimum merchantable size will be when he reenters the stand to make his first commercial thinning. One realistic management objective is to obtain a return from the stand at the earliest possible date and insure the continued rapid growth of the residual stand. In general, a commercial thinning shortly after the stand reaches the merchantable limit will more than cover costs. Frequently part of past investments in precommercial thinning, regeneration, and "land rent" can be recovered also. This effectively reduces interest costs, whether implied (public lands) or an actual account charge (private land).

On the Boise National Forest in Idaho, the minimum merchantable conifer is about 10 inches d.b.h. One sale of ponderosa pine, with an 8-inch size limit, was cut at Boise Basin Experimental Forest in late 1971. At the Fort Valley Experimental Forest, Arizona, ponderosa pine trees 6 inches d.b.h. are merchantable for pulpwood (Schubert 1971).

Economic maturity guides (Teeguarden 1968) for site index 157_{100} (Arvanitis and others 1964, comparable to Myers 1938) suggest we should not carry ponderosa pine stands dedicated to sawtimber production beyond 16 inches d.b.h. The Forest Service Manual (2415.21 1972) suggests 17 to 20 inches. Where other objectives override, such as in travel influence zones, responses of larger diameter trees may still be estimated with this system. Naturally, older trees will not attain the site rings per inch growth potentials.

Step 4.--Establishing the Reentry Year

The proposed reentry year is critical to the success of this method. The treatment prescription is determined by the time between the last precommercial thinning and the first commercial thinning. We work backwards from a future objective. An important implication is: *Once a stand is brought under management there is a commitment to follow through with future harvests.* This is doubly important if treatment is necessary to sustain growth rates where forestwide harvest levels have been based on the allowable cut effect (Schweitzer and others 1972).

Realistically, the level of refinement of today's growth estimates suggests that the proper reentry year may vary by ±20 percent of the time period between harvests. If the first commercial harvest (reentry date) is proposed for 12 years after thinning, it would be reasonable to check the stand ring-per-inch growth rates and basal area at 10 years and to adjust the reentry year to 13 or 11 if necessary. At this time, a very precise reentry date can be proposed. The value of such precision for management practices should not be overlooked; establishment of a proper reentry year and adherence to it are necessary to maintain high tree growth levels and to assure recovery of earlier investments.

Step 5.--Estimating Minimum Operable Volume Per Acre

A logger must have a majority of paying operations to stay in business. Both size of material and volume per acre removed are important. Of course, equipment should be geared to efficiently handle the size of material being logged.

Volume per acre influences costs and returns for each landing or loading setup, and other costs which are prorated on an area basis. We have little data to suggest the "break-even" volume per acre. It appears that efficient and flexible operations are possible with 1 to 1.5 thousand board feet per acre on easy ground with good access and mills nearby. The land manager must provide the "break-even" estimate for each situation on the basis of local conditions.

GRAPHIC SOLUTIONS WITH PONDEROSA PINE

All five factors may be brought together in a single graph having 2-cycle logarithmic scales (fig. 3). The stand density index of Reineke (1933) follows the same form as figure 3. Reineke's units are relatives, *i.e.* percent of normal stocking, based on a yield table, while these units are in absolute values, *i.e.* square feet of basal area. Meyer (1938) adjusted the stand-density index to fit his data for ponderosa pine and used, as the index values, the number of stems at 10 inches d.b.h., *i.e.* stand-density index of 200 means 200 10-inch trees or a comparable number for other diameters. Meyer's adjustment for curvature has little significance in the stocking range considered here. The physical relationships of d.b.h., stems per acre (SPA), spacing and stand basal area (BA) are the base:

$$\text{Log SPA} = 5.20788 - 0.99455 \text{ Log } (\text{DBH}^2) + 0.99451 \text{ Log BA}$$

and, spacing in feet (FT):

$$\text{FT} = \sqrt{43560/\text{SPA}}$$

D.b.h. growth for representative RPI rates and reentry periods are inset in a table. Estimates of rings-per-inch growth potential over time (reentry period), the basal area stocking standard, and the merchantability and operable volume limits are specified for each management situation.

Example

Let's see how the model for precommercial thinning in an even-aged ponderosa pine stand works. Letters in parentheses in this example refer to the same letters on figure 3. We will assume a set of data for one stand of uniform Site Index 70_{100} or 43_{50} (Meyer 1938). Stump observations suggest a 6-ring-per-inch growth rate potential (A). We assume that 45 ft^2 basal area is the stocking limit (B). The stand presently averages 4 inches d.b.h. (C) on the 100 largest trees and is 30 years old. Estimated tree merchantability in 10+ years is 8 inches d.b.h. (D). At 6 rings-per-inch (RPI) the stand will reach the estimated merchantability limit in 12 years.

$$(8 \text{ inches} - 4 \text{ inches}) \times 1/2 \times 6 \text{ RPI} = 12 \text{ years.}$$

Notice that we are starting with a future objective and point in time and will work backwards to the thinning standard.

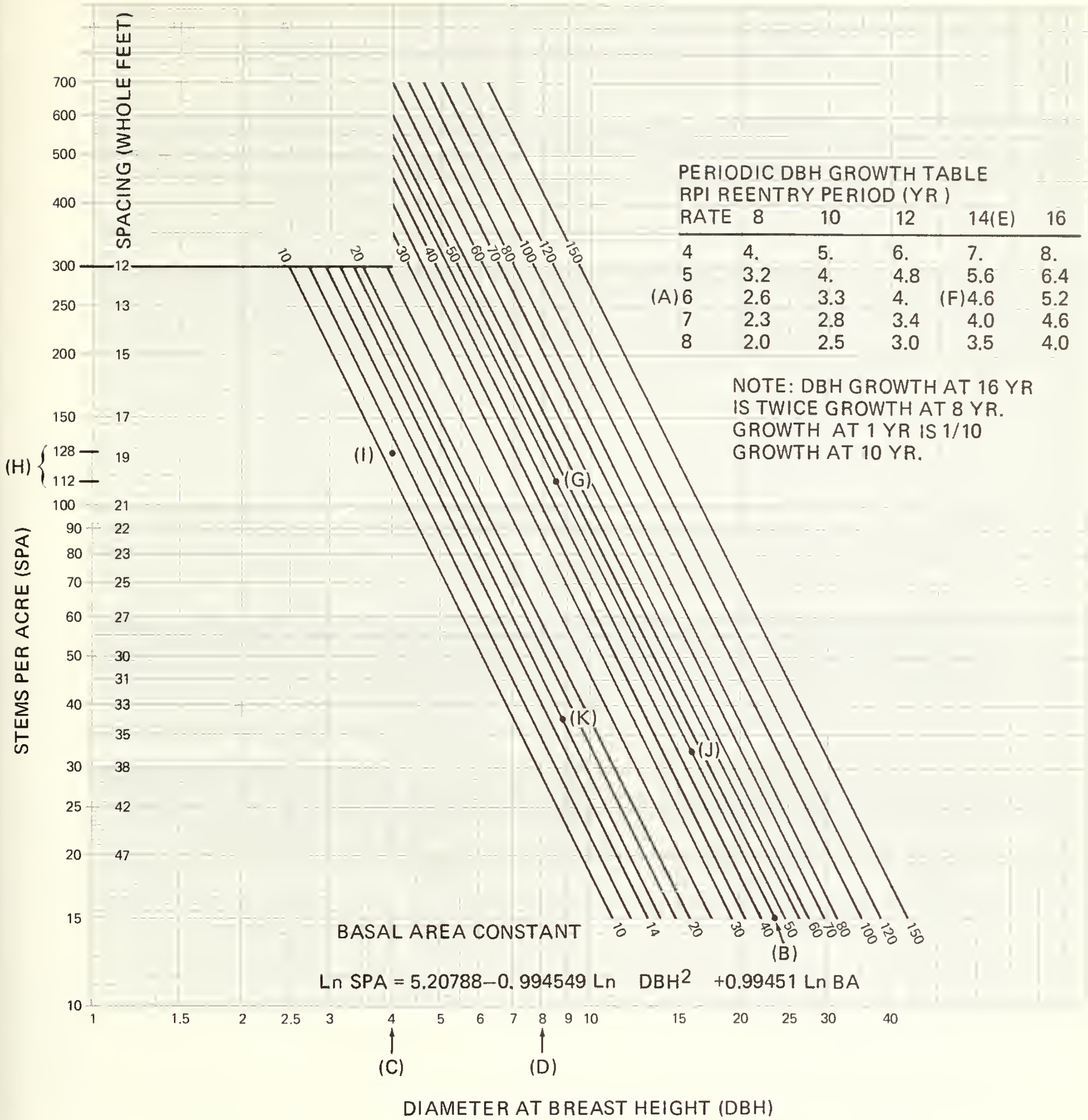


Figure 3.--Average diameter at breast height, stems per acre/spacing relations for constant basal area factors. SPA = stems per acre; DBH = diameter at breast height.

Let's assume that plans for year 12 (reentry period) prevent us from making the thinning; *i.e.*, thinning crews, processing plant capacity, or area for allowable cut are fully committed. We must defer treating this stand for 2 more years--to year 14 (E). By year 14 we will have added 4.6 inches of d.b.h. growth (F) and we want to arrive at our basal area standard of 45 ft^2 with trees 8.6 inches d.b.h. (G). Looking to the vertical axis we find there will be 112 stems per acre spaced an average of 19.7 feet apart (H). To check, an 8.6-inch tree has 0.4034 ft^2 basal area here. Hence,

$$45 \text{ ft}^2 \text{ BA}/.4034 \text{ ft}^2 = 112 \text{ trees per acre}$$

Over a 14-year period we can assume there will be some mortality. Assuming 1.0 percent per year mortality for 14 years, compounded annually, the interest factor is 1.145 (Marty and Neebe 1966; Forbes 1956; or other forest management texts). Thus, including predicted mortality we should thin to leave:

$$112 \text{ SPA X } 1.149 \text{ factor} = 128 \text{ SPA} \quad \text{(H)}$$

Average spacing should be:

$$\sqrt{43560 \text{ ft}^2 \text{ per acre}/128 \text{ SPA}} = 18.5 \text{ ft between trees}$$

A tree 4 inches in d.b.h. has 0.0873 ft^2 basal area. Thus after thinning to 128 SPA the basal area stocking should average:

$$128 \text{ SPA X } 0.0873 \text{ ft}^2 = 11.2 \text{ ft}^2 \text{ BA}_6\text{--about } 11 \text{ ft}^2 \text{ (I).}$$

In summary, we have a stand of 4-inch trees capable of growing at a 6-ring-per-inch rate. Thinning these trees now to 11.2 ft^2 BA (128 SPA) should, with 1 percent mortality per year, bring the stand to 45 ft^2 BA in 14 years with 112 stems per acre averaging 8.6 inches d.b.h.

DISCUSSION

This interim method for setting thinning standards can help forest managers recognize tree growth potentials and insure sufficient spacing to permit full stand responses over the desired time span. These standards should improve economic returns by tailoring the stand to fit the growth period and site potentials and by insuring the fullest stand response for the thinning investment. Volume growth will occur on fewer stems, shortening the period to reach prescribed size objectives.

Basal area standards may be modified to attain other objectives. Steep slopes may require heavier stocking to control erosion. Lighter stocking may produce more forage for wildlife winter range or cattle allotments.

Logging disturbance of slope-protective vegetation may dictate longer growth periods. Greater logging costs may also suggest longer growth periods to increase the volume cut per acre.

If maximum periodic diameter growth is not one of the objectives of a thinning, the forest manager must establish other relationships to reach his objective. Results from the western regional growing-stock-level studies will help establish stocking-diameter growth relationships to achieve less than maximum periodic diameter growth.

Tree and wood quality characteristics have not been considered in this method. Consideration of relative wood density and uniformity of growth rings as influenced by growth rates and stocking should be included as data become available. Branch characteristics and tree form as related to stocking are other areas needing study before inclusion.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 — 677-087 / 6 REGION NO. 8

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-184

August 1974

GENETIC VARIATION OF DOUGLAS-FIR IN THE NORTHERN ROCKY MOUNTAINS

G. E. Rehfeldt[1]

ABSTRACT

Seven half-sib families from each of 24 populations were compared to assess genetic variation in 2-year height of Douglas-fir (Pseudotsuga menziesii *var.* glauca) *seedlings. Families from* Pseudotsuga menziesii-Calamagrostis rubescens *and* Abies lasiocarpa-Pachistima myrsinites *habitat types had lower mean heights than those from four other habitat types. Families from western Montana had lower mean heights than those from northern Idaho and eastern Washington, regardless of the habitat type and elevation of the seed source. Thirteen percent of the total variance was attributable to variation among half-sib families within populations.*

Adaptive genetic variation among populations develops through selection by natural environments. Thus, genetic variation may accumulate in species, such as Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), that occur across broad environmental spectra. Environmental heterogeneity in the northern Rockies is partially discernible in terms of habitat types developed for northern Idaho and eastern Washington (Daubenmire and Daubenmire 1968) and for western Montana by Pfister and others (reports being reviewed). In both areas, Douglas-fir occurs across a broad range of environmental conditions: from the relatively low and dry sites on which Douglas-fir is climax, through the moist sites dominated by western redcedar and western hemlock, to the relatively cold sites dominated by subalpine fir. Ample opportunity exists for development of adaptive variation in Douglas-fir of the northern Rockies.

Previous studies have shown that within a particular locality, populations of Rocky mountain Douglas-fir were not differentiated according to contrasting microclimates associated with north or south aspects at elevations from 950 to 1,300 m. Nevertheless, relatively large proportions of genetic variance were associated with populations and families within populations (Rehfeldt 1974). Genetic variation on a larger geographic scale is further explored in the present study of Rocky Mountain Douglas-fir.

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[1]Research Geneticist, stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, which is maintained in cooperation with the University of Idaho.

MATERIALS AND METHODS

Cones were collected from seven trees in each of 24 populations (table 1) located within the area bounded by the Canadian border, the Columbia River, the Salmon River, and the Continental Divide. Four populations represented each of six habitats: (1) DF/Phma[2] = *Pseudotsuga menziesii-Physocarpus malvaceus* and DF/Syal = *Pseudotsuga menziesii-Symphoricarpos albus*, (2) DF/Caru = *Pseudotsuga menziesii-Calamagrostis rubescens*, (3) GF/Pamy = *Abies grandis-Pachistima myrsinites*, (4) WRC/Pamy = *Thuja plicata-Pachistima myrsinites*, (5) WH/Pamy = *Thuja plicata-Pachistima myrsinites*, and (6) AF/Pamy = *Abies lasiocarpa-Pachistima myrsinites*. DF/Phma and DF/Syal habitats were grouped because both represent relatively dry sites at relatively low elevations on which Douglas-fir is climax. An attempt was made to maximize geographic distances and elevational differences among populations representing the same habitat type.

Seeds were sown in a randomized complete block design consisting of two replicates at the USDA Forest Service Nursery at Coeur d'Alene, Idaho. In 1973, heights of the tallest 2-year-old trees within each sixth of each plot were measured. An analysis of variance (table 2) for a hierarchial model of random effects (Steel and Torrie 1960) was made on the original measurements.

Table 1.--*Location, physiographic setting, and mean height of seedlings for each population*

Population	Latitude	Longitude	Nearest community	Habitat type	Elevation	Mean height
					m	*cm*
1	48°55'	116°20'	Copeland, Idaho	DF/Phma	594	29.3
2	48°50'	114°50'	Eureka, Mont.	DF/Syal	1,116	23.4
3	47°35'	116°40'	Coeur d'Alene, Idaho	DF/Phma	701	27.4
4	46°05'	114°15'	Darby, Mont.	DF/Syal	1,280	20.6
5	48°40'	118°20'	Kettle Falls, Wash.	DF/Caru	1,219	21.9
6	48°10'	115°30'	Libby, Mont.	DF/Caru	1,753	13.7
7	46°50'	113°25'	Greenough, Mont.	DF/Caru	1,875	19.3
8	45°45'	114°30'	West Fork RD, Mont.	DF/Caru	1,875	13.9
9	48°00'	116°55'	Spirit Lake, Idaho	GF/Pamy	780	30.5
10	47°55'	114°00'	Bigfork, Mont.	GF/Pamy	975	27.2
11	45°45'	116°00'	Grangeville, Idaho	GF/Pamy	1,463	28.0
12	47°10'	114°35'	Stark, Mont.	GF/Pamy	1,158	20.2
13	48°40'	117°35'	Alladin, Wash.	WRC/Pamy	1,158	24.9
14	48°20'	116°15'	Hope, Idaho	WRC/Pamy	1,265	25.4
15	46°30'	115°50'	Pierce, Idaho	AF/Pamy	1,000	15.8
16	47°30'	113°35'	Seeley Lake, Mont.	WRC/Pamy	1,390	23.5
17	48°20'	116°50'	Coolin, Idaho	WH/Pamy	975	30.6
18	48°35'	115°20'	Warland, Mont.	WH/Pamy	1,128	26.3
19	47°00'	116°10'	Clarkia, Idaho	WH/Pamy	1,143	26.7
20	47°40'	115°10'	Thompson Falls, Mont.	WH/Pamy	1,109	25.9
21	48°15'	117°35'	Chewelah, Wash.	AF/Pamy	1,676	15.3
22	48°25'	114°35'	Whitefish, Mont.	AF/Pamy	1,091	20.8
23	47°30'	115°40'	Burke, Idaho	AF/Pamy	1,356	20.9
24	46°30'	115°00'	Powell, Idaho	WRC/Pamy	875	28.8

[2]Abbreviations preceding formal nomenclature for habitat types will be used in the remainder of this paper.

Table 2.--*Form and results of analysis of variance of 2-year height*

Source of variance	Degrees of freedom	Unweighted components expected in each mean square	Intraclass correlation
Replication	1	$\sigma^2_E + \sigma^2_{RF} + \sigma^2_R$	25.2**
Families	167	$\sigma^2_E + \sigma^2_{RF} + \sigma^2_F$	46.0**
Habitat types[1/]	5	$\sigma^2_E + \sigma^2_{RF} + \sigma^2_{F/P/H} + \sigma^2_{P/H} + \sigma^2_H$	15.4**
Populations within habitats[1/]	18	$\sigma^2_E + \sigma^2_{RF} + \sigma^2_{F/P/H} + \sigma^2_{P/H}$	17.2**
Families within populations[1/]	144	$\sigma^2_E + \sigma^2_{RF} + \sigma^2_{F/P/H}$	13.5**
Replication X Families	167	$\sigma^2_E + \sigma^2_{RF}$	17.0**
Error	1,638	σ^2_E	11.9

[1/]Subdivisions of the effects of families.

** Statistical significance of *F* values at the 1 percent level of probability.

RESULTS AND DISCUSSION

Forty-six percent of the total variance in seedling height was associated with half-sib families (table 2). Effects of habitat types, populations within habitat types, and families within populations contributed nearly equally to the family variance. Thus, substantial proportions of genetic variance occur for each level of classification.

Effects of habitat types resulted primarily from low mean heights of seedlings representing DF/Caru and AF/Pamy types as shown in the following tabulation:

Habitat type	*Height*
	cm
DF/Phma and Syal	25.2
GF/Pamy	26.5
WRC/Pamy	25.7
WH/Pamy	27.4
DF/Caru	17.2
AF/Pamy	18.2

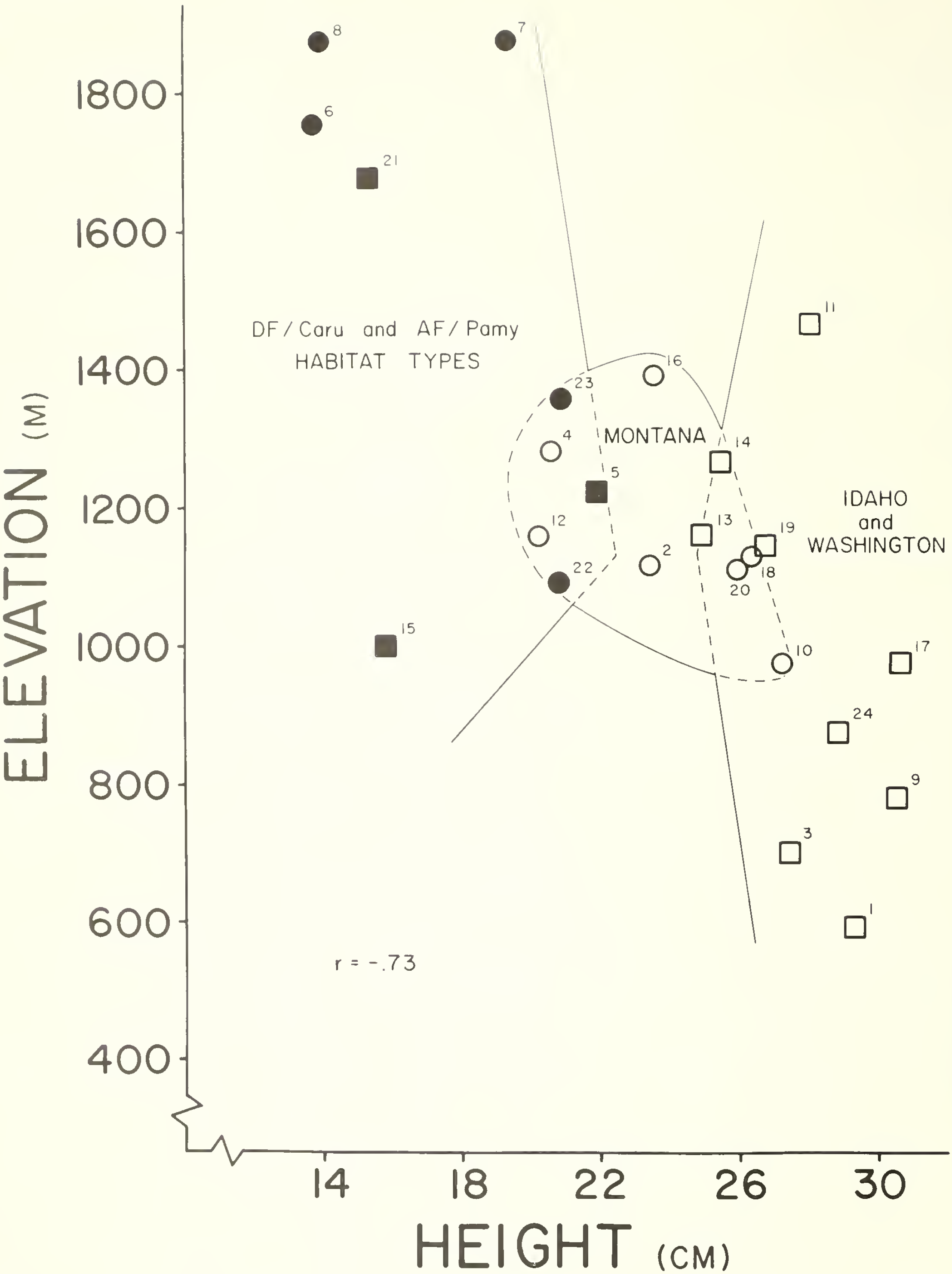

Figure 1.--Relationship between 2-year height of progenies and elevation of their origin. Square symbols = Idaho and Washington populations; round symbols = Montana populations; solid symbols = DF/Caru and AF/Pamy habitats. Numbers coding each population are keyed to Table 1.

Mean heights of seedlings from these two habitat types were significantly lower (5 percent level of probability) than those of seedlings from all other habitat types when the "S" test for multiple mean comparisons (Scheffé 1958) was applied. Evidently, pressures of selection associated with relatively cool DF/Caru and AF/Pamy habitats deviate sufficiently from those of other habitats to cause genetic differentiation.

Large effects for populations indicate that genetic differentiation is not solely interpretable in terms of habitat types. Indeed, the six populations of greatest mean seedling height were from Idaho (table 1). Scheffé's "S" test indicated significantly greater (5 percent level) mean heights associated with the group of populations from northern Idaho and eastern Washington than for those from western Montana, whether or not populations representing DF/Caru and AF/Pamy habitat types were excluded from the analysis. Differences between families from Idaho and those from Montana were also apparent in progeny tests conducted in the Midwest (Wright and others 1971). Evidently, the crests of the Bitterroot and Cabinet Mountains divide areas of contrasting selection pressures.

Mean heights of seedlings from each population and elevation where the populations occurred showed a significant ($r = -0.73$, 1 percent level) correlation (fig. 1). Although significant correlations between seedling height and elevation of the seed source are not uncommon (Roche 1969), the correlation observed with Douglas-fir is interpretable ecologically. In general, populations representing DF/Caru and AF/Pamy habitat types were from the highest elevations but were associated with the lowest mean heights. However, populations 15 and 22 represented the AF/Pamy habitat type in frost pockets at relatively low elevations; yet the mean height of families from these populations was similar to that of populations from AF/Pamy and DF/Caru habitats at the high elevations. Differentiation of populations from these habitat types appears to be a function of the cool environment associated with the habitat.

When the eight populations from DF/Caru and AF/Pamy habitat types are eliminated from the correlation procedure, the coefficient is reduced to -0.57 (significant at the 5 percent level). However, on the average, Montana populations had shorter families but were from higher elevations than those from Idaho and Washington. That differentiation of these groups is related to geography rather than elevation is suggested by the height of progenies from population 11; this Idaho population was from a relatively high elevation, but the mean height of its families was similar to that of families from Idaho and Washington (fig. 1). Moreover, significant correlations between height of families and elevation of the seed source were not observed within either the Montana or the Idaho and Washington groups. Differentiation appears to be related to geographic and ecologic factors which are intercorrelated with the elevation of the seed source.

Definition of large proportions of genetic variance for Rocky Mountain Douglas-fir can serve as a guide to forest management. The combination of these results with those suggesting a lack of local variation associated with aspect and elevation (Rehfeldt 1974) implies a minimum of three seed zones for the region under study: (1) DF/Caru and AF/Pamy habitat types, (2) western Montana, excluding DF/Caru and AF/Pamy habitats, and (3) northern Idaho and eastern Washington, excluding DF/Caru and AF/Pamy habitats. These three groupings collectively account for approximately 54 percent of the genetic variance. However, three seed zones are minimal; they are recommended on the basis of only one study conducted in only one environment for only one trait. Final definition of seed zones must be based on analyses of traits that depict the fitness of populations in a variety of natural environments.

Gains in productivity by means of tree breeding result from selective utilization of the genetic variance among families. Although 46 percent of the total variance was attributable to half-sib families, this value does not accurately estimate the half-sib component of variance because: (1) the progeny test was conducted in only one environment and, therefore, estimated components contain effects due to interaction between genotype and environment; (2) only the tallest trees were measured within each plot and, therefore, error variances are probably underestimated; and (3) late spring frosts in 1973 caused substantial injury to developing buds on seedlings from certain families and populations. Although seedlings exhibiting pronounced effects of frost were not measured, differential injury nonetheless caused inflation of components of variance for half-sib families. For these reasons, the component of variance for families within populations (table 2) presumably estimates most accurately the half-sib component. The intraclass correlation for this effect was about 13 percent, a value that corresponds almost precisely to previous results (Rehfeldt 1974). Thus, 13 percent of the total variance is available for tree improvement; substantial proportions of additive genetic variance occur within Douglas-fir of the northern Rocky Mountains.

ACKNOWLEDGMENT

Materials studied are being included in combined progeny test-seed orchards being established by the Intermountain Forest and Range Experiment Station and the Northern Region of the USDA Forest Service. The author gratefully acknowledges cooperation by G. E. Howe, geneticist; L. L. Mason, nurseryman; M. J. Morton and other personnel at the USDA Forest Service Nursery at Coeur d'Alene.

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Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-185

September 1974

TETRAZOLIUM VIABILITY, GERMINABILITY, AND SEEDLING GROWTH OF OLD SEEDS OF 36 MOUNTAIN RANGE PLANTS

Walter T. McDonough[1]

ABSTRACT

Seeds of 36 species of mountain range plants (6 trees, 12 grasses, 18 forbs) collected during 1928-31 at the Great Basin Experiment Station in Ephraim Canyon, Utah, were tested for viability and germinability in 1972. Twenty-nine species gave negative reactions in the tetrazolium seed viability test. The remaining species (3 grasses, 4 forbs), when tested for germination at each of three temperature alternations in the 25° to 5°C range, and at a stratification temperature, yielded low to intermediate percentages at two or more of the test temperatures. Survival of seedlings transplanted to the greenhouse was generally good, but only Agoseris glauca *completed the growth cycle to seed-set. Progeny (F_1) seeds of* A. glauca *failed to germinate unless the embryo was isolated by removal of the external tissues.*

Numerous investigations have been carried out on the viability in old seeds, as reviewed by Crocker (1945) and Quick (1961). Seeds of 8 of 20 common weed species buried in soil by Beal in 1879 retained germinability 40 years later (Kivilaan and Bandurski 1973). Tiedemann and Pond (1967) obtained germination in 4 of 20 species of grasses after 20 years storage under uncontrolled conditions. Hull (1973) examined seeds of 60 rangeland species that had been stored in an unheated shed for varying period of 14 to 41 years. All grass species lost germinability after 27 years; shrubs after 20 years and, among forbs, only *Erodium cicutarium* attained appreciable longevity (37 years).

Generalizations regarding the basis for the longevity of seeds are few (Crocker 1945, Quick 1961, Abdul-Baki and Anderson 1972). Certain anatomical and morphological characteristics of the seed, such as an indurated testa or pericarp, tend to promote longevity by reducing harmful fluctuations in the water content of the tissues. Natural storage conditions (in soil in the field) or proper laboratory treatments (drying and storing the seeds in sealed containers under refrigeration) also promote longevity. Loss of germinability with age probably results from denaturation of protein and nucleic acids of the genetic material. Aged seeds and derived seedlings characteristically exhibit reduced germination compared to new seed, changes in environmental requirements for germination, and slow, sometimes abnormal seedling growth.

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[1] Plant Physiologist, stationed in Logan, Utah, at Forestry Sciences Laboratory, maintained in cooperation with Utah State University.

MATERIALS AND METHODS

Seeds that had been collected on high elevation range in Ephraim Canyon, Utah, between 1928 and 1931 for a study involving the effects of alternate wetting and drying on germination (Griswald 1936) were tested for germinability in 1972. The 41 to 44 year-old-seeds of 36 species had been stored in paper packets in a building of the Great Basin Experiment Station under uncontrolled conditions. Included were 6 species of trees, 12 grasses, and 18 forbs.

A preliminary screening for tetrazolium viability (Moore 1969; Abdul-Baki and Anderson 1972) was made on 50 seeds of each species. The seeds were imbibed on water-saturated filter paper in petri dishes for 6 hours before being bisected longitudinally. The halves were immersed in 25 ml portions of 1 percent aqueous 2, 3, 5-triphenyl-2H-tetrazolium chloride for 6 h in the laboratory before color evaluations were made. Seeds of those species that gave a positive color reaction in any percentage were tested for germination.

Germination tests were made with filter paper saturated with distilled water in 9-cm petri dishes (Florez and McDonough, 1974). Three daily temperature alternations (25°/15°C, 20°/10°C, 15°/5°C) were used. Seeds were exposed to the higher temperature for 8 h and then to the lower for 16 h. Eight h photoperiods coincided with the higher temperature of the alternation. Four replications of each temperature treatment were made with 25 or 50 seeds per dish. Tests were run for 30 days with examinations for germination (visible root protrusion) every third day. Other sets of 25 or 50 seeds per dish with four replications were stratified for 120 days at 2° ± 1°C before examination for germination. Ungerminated seeds were then transferred to 30 days of temperature alternation (20°/10°C) and examinations.

New seeds of several of the species were collected in 1972 on the same old collection sites in Ephraim Canyon and tested for germination under the same conditions. Other germinability comparisons were based on results published by Griswald (1936) and on collections made in the late 1960's on high elevation range on the Dixie and Uinta National Forests in Utah (McDonough 1969; 1970).

Plant hormones or other biochemicals known to promote germination in old and dormant seeds--biochemicals that might substitute for natural constituents that had deteriorated or for which the synthesizing systems had deteriorated--were applied to old seeds showing some germinability in an attempt to increase the germination percentages. The biochemicals used were ethylene (Takayanagi and Harrington 1971), gibberellin A_3, A_7, kinetin (Wareing and Saunders 1971), and ribonulease (Wurzburger and Leshem 1971). Concentrations and methods of application were taken from the literature. Procedures and incubation temperatures were the same as those in the principal experiment.

Seedlings derived from germination of old seeds were planted in mountain topsoil, two seedlings per 20 l container, to determine survival and growth over a 4-month period under greenhouse conditions. Surviving plants that showed arrested development were then placed in a cold room at 2° ± 1°C for 4 months before return to the greenhouse for an additional 4 months of observation.

In another experiment, embryos of progeny (F_1) seeds of *Agoseris glauca* were isolated from the external tissues (endosperm and pericarp) by imbibing for 8 h, slitting the external tissues near the root end with a dissecting needle, and extruding the embryo by pushing against the cotyledonary end.

RESULTS AND DISCUSSION

Of the 36 species, 29 were negative in the tetrazolium test:

TREES

Abies concolor (Gord. & Glend.) Lindl.
Acer glabrum Torr.
Picea engelmannii Parry
Pinus flexilis James
Pseudotsuga menziesii (Mirb.) Franco
Quercus gambelii Nutt.

GRASSES

Agropyron trachycaulum (Link) Malte
A. riparium Scribn. and Smith
Bromus inermis Leyss.
B. polyanthus Scribn.
B. porteri (Coult.) Nash
Hordeum depressum (Scribn. and Smith) Rydb.
Poa nervosa (Hook.) Vasey
P. nevadensis Vasey
P. sandbergii Vasey

FORBS

Achillea millifolium L.
Aquilegia caerulea James
A. flavescens S. Wats.
Artemisia ludoviciana Nutt.
Chenopodium album L.
Descurainia pinnata (Walt.) Britton
Gilia aggregata (Pursh) Spreng.
Heracleum lanatum Michx.
Osmorhiza occidentalis (Nutt.) Torr.
Penstemon rydbergii A. Nels.
P. subglaber Rydb.
Pontentilla gracilis Dougl.
Rumex mexicanus Meisn.
Senecio serra Hook.

Seven species with 12 to 92 percent positive tetrazolium reaction germinated at two or more of the alternating temperatures or at 2°C (table 1). There was no additional germination of stratified seeds after transfer to 20°/10°C. Germination of *Agoseris glauca* and *Melica bulbosa* was appreciable throughout the range of test temperatures. Germination in the other five species was minimal, with temperature preferences at the low end for *Stipa* spp., at the intermediate level for *Agastache urticifolia* and *Moldavica parviflora*, and without a trend in *Polemonium foliosissimum* (table 1).

Table 1.--*Germination percentages of old seed at three temperature alternations and at 2°C*

Species	Temperature alternation (8/16 h) 25°/15°C	20°/10°C	15°/5°C	2°C
Agastache urticifolia (Benth.) Kuntze	2	5	3	1
Agoseris glauca (Pursh) Raf.	12	47	44	36
Melica bulbosa Geyer	41	34	58	37
Moldavica parviflora (Nutt.) Britton	0	6	2	0
Stipa columbiana Macour	1	7	12	15
S. lettermani Vasey	0	0	4	1
Polemonium foliosissimum A. Gray	4	0	1	0

Germination of new seed of *S. columbiana* and *S. lettermani* from Ephraim Canyon gave maximum percentages of 77 and 64, respectively, at 15°/5°C. Similarly, *A. urticifolia* yielded 87 percent at 20°/10°C. In new collections from other high elevation sites in Utah, *A. glauca* germinated 24 percent at temperature alternations of 17°/12°C, and to a total of 77 percent during 8-week stratification and after transfer to 22°/17°C (McDonough 1970). *M. bulbosa* germinated 41 percent during and after stratification, but not at higher temperatures, while *P. foliosissimum* germinated 61 percent at 22°/17°C (McDonough 1969). New collections were not available for *M. parviflora*.

Griswald (1936) reported results on five of the species listed in table 1. Tests were carried out mostly at uncontrolled temperatures in the laboratory or greenhouse. Maximum germination percentages were *M. bulbosa* (94), *M. parviflora* (4), *P. foliosissimum* (30), *S. columbiana* (84), and *S. lettermani* (98). The low germination percentage for *M. parviflora* probably resulted from a dormancy that was not relieved by any of the treatments applied. Since the old seeds of *M. parviflora* reacted 68 percent positive in the tetrazolium test, it is possible that more were germinable but had a dormancy not relieved by any of the test conditions.

The comparisons of germinability in old and recent collections of the seeds, and in initial and 40+ year determinations in seeds of the same collections, show the expected results of generally reduced germination in the old seeds. Exceptions were *A. glauca*, where the range of temperature conditions for germination of the old seeds was broader, and *M. bulbosa*, where a stratification requirement may have been eliminated by the aging. However, varying site factors or ecotypic differentiation could be influential here.

Attempts to increase germinability in the old seeds listed in table 1 by application of biochemicals failed. Germination percentages either did not differ significantly or the treatment reduced germination below the water controls.

Seedling survival generally was good, but only *A. glauca* seedlings developed to seed-set (table 2). The grasses and *M. parviflora* did not progress beyond the juvenile stage during the first growth period, and the plants died during or following the low temperature treatment. *A. glauca* set seed during the first growth period; the other forbs required stratification for flowering (*A. urticifolia*) and for stem elongation without flowering (*P. foliosissimum*) during the second growth period.

Table 2.--*Survival and extent of growth of seedlings derived from old seed*

Species	Seedlings: Planted	Seedlings: Survived		Extent of growth and development
		No.	*Percent*	
Agastache urticifolia	22	13	59	Flowering, no seed
Agoseris glauca	127	86	68	Seed-set
Melica bulbosa	149	38	25	3-5 leaf stage
Moldavica parviflora	8	3	37	8-14 leaf stage (rosette)
Stipa columbiana	35	7	20	1-3 leaf stage
S. lettermani	5	0	0	1-3 leaf stage
Polemonium foliosissimum	10	4	40	Stem elongation

Progeny seeds of old *A. glauca* did not germinate at the test temperatures, and averaged only 7 percent during and after stratification. Seeds under stratification showed a bulging of the root tip region of the seed, but no penetration of the external tissues. Under the assumption that these tissues were impeding germination by mechanical restraint, the tests were rerun with isolated embryos. Following this treatment, extensive germination (embryo growth) occurred under all temperature treatments from a minimum of 83 percent at 25°/15°C to 91 percent at 15°/5°C.

Loss of germinability with age has been attributed to the onset of chromosomal abnormalities (Abdul-Baki and Anderson 1972) that may result in nonfunctioning biochemical systems vital to germination. Kivilaan and Bandurski (1973) grew 10 seedlings from 90-year-old seeds of *Verbascum blattaria* through a normal growth and development cycle to seed-set. Germination of progeny seeds was significantly lower than germination of new seeds collected from the same site. The lower germination in the progeny seeds was thought to be due to the accumulation of deleterious mutations in the aged seeds or derived plants, mutations transmitted to the progeny seeds. In old *Agoseris glauca,* a block to germination becomes obvious in the progeny seeds where growth of the embryo is insufficient to penetrate the external tissues. Whether germination of the old seed (table 1) could have been increased with isolated embryos was not determined because of insufficient seed.

The percentage of species in the collection showing a complete loss of viability, and the range of germination percentages in the remainder generally are comparable to other determinations in collections of weed and range plants (Tiedemann and Pond 1967; Hull 1973; Kivilaan and Bandurski 1973). Since the two species showing the greatest retention of viability (*A. glauca, M. bulbosa*) have no obvious morphological modifications that might be expected to enhance longevity, vital protein and nucleic acid constituents of the seeds of these species may be inherently more stable than average.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 — 677-088 / 10 REGION NO. 8

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USDA FOREST SERVICE RESEARCH NOTE INT-186

WATER QUALITY OF THREE SMALL WATERSHEDS IN NORTHERN UTAH

Robert D. Doty and Ezra Hookano, Jr.[1]

ABSTRACT

The chemical, physical, and bacteriological characteristics of streamflow from three small adjacent drainages in the Wasatch mountains of northern Utah are tabulated and discussed. These watersheds are sufficiently undisturbed so their chemical water quality essentially reflects their natural characteristics. Though man's presence here is minimal and livestock are excluded, the bacterial load in these streams indicates some pollution by warmblooded animals. Suspended sediment is negligible.

This report summarizes the chemical, physical, and bacteriological characteristics of streamflow from three small watersheds within the Davis County Experimental Watershed of northern Utah (fig. 1). Although this portion of the Wasatch Mountains was severely abused in the past, it has been protected since 1930 from fire, domestic livestock grazing, and timber cutting. These 45 years of protection have returned this area to near pristine conditions. The reported data can be considered as benchmark measures of streamflow quality from drainages with limited recent impact by man.

The three watersheds occupy adjacent south-facing slopes that drain into Farmington Creek and lie within the 6,000- to 9,000-foot elevation zone. The Halfway Creek, Corduroy Creek, and Whipple Creek catchments occupy 464, 140, and 359 acres, respectively. The Corduroy watershed has been essentially undisturbed since 1930; Whipple has a two-lane gravel road parallel to the upper border; and the upper 15 percent of Halfway was contour trenched in 1964. A comparison of streamflow measurements before and after this trenching showed no significant change in water yields (Doty 1971).

All three streams have steep (30 to 40 percent) gradients and "V"-shaped channels which eroded to bedrock prior to the mid-1930's. These channels are now becoming stabilized.

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October 1974

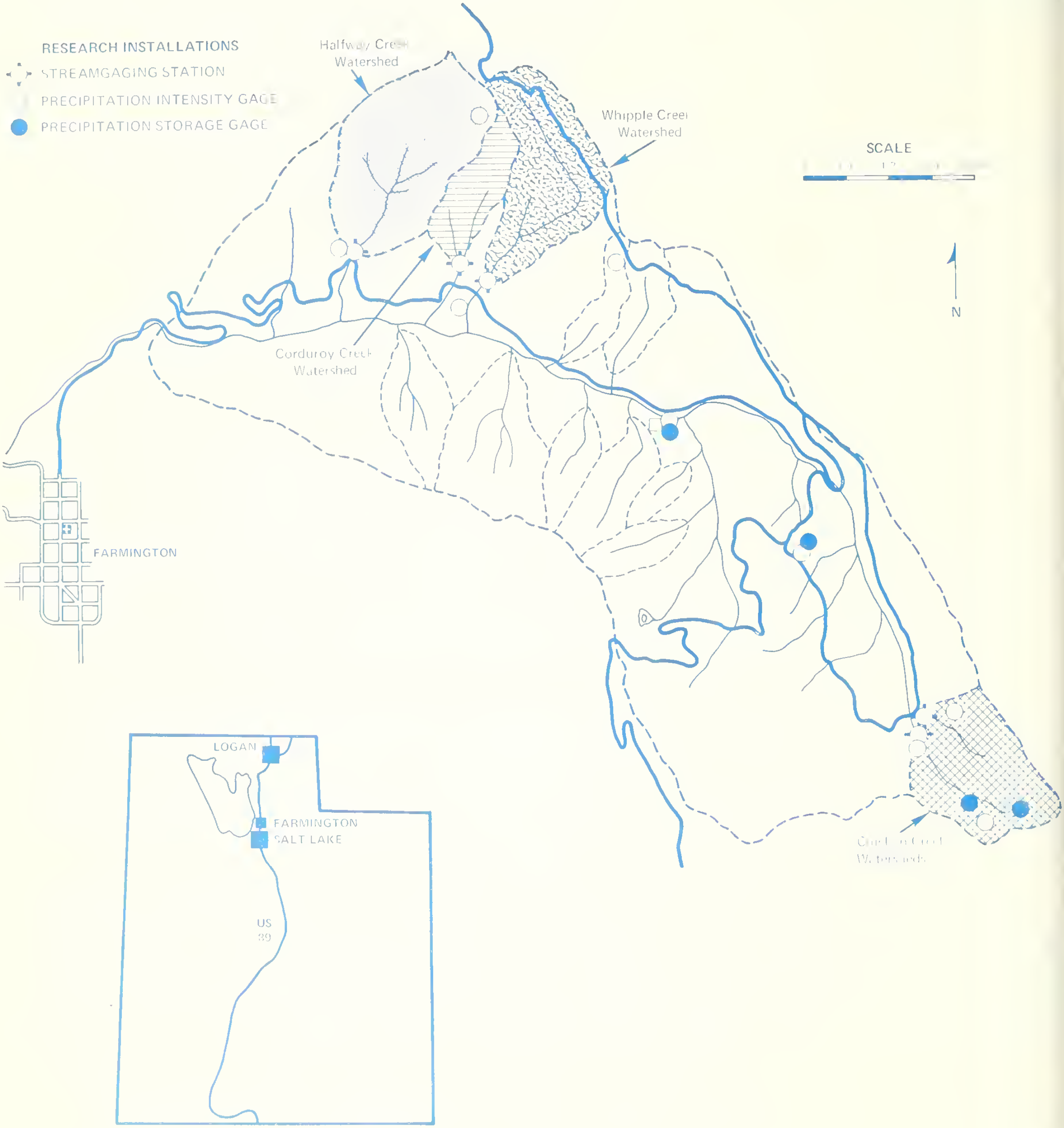

Figure 1.--The Halfway, Corduroy, and Whipple Creek watersheds in the Farmington Canyon drainage. Interpretive data were obtained from the Chicken Creek watersheds.

Soils are coarse textured, immature, rocky, and shallow (Doty 1971). The parent material is a complex of Precambrian metamorphic rocks (Bell 1952), referred to as the Farmington Canyon Complex by Eardley and Hatch (1940). These rocks are divided into four facies and subfacies from green schists to granulite.

Dense oakbrush (*Quercus gambelii* Nutt.) occupies the lower elevations. Intermediate elevations have extensive brush fields, mostly of *Ceanothus velutinus* Dougl. Two species of sagebrush (*Artemisia tridentata* Nutt. and *A. scopulorum* A. Gray) with a ground cover of grasses and forbs grow on drier midslopes and the upper ridges.

Two-thirds of the annual streamflow volume results from snowmelt during the March through June period (Doty 1971). Streamflow during the remainder of the year is almost exclusively from deep seepage and interflow. Most summer storms are light; less than 2 percent of summer precipitation results in direct runoff (Croft and Marston 1950); but the runoff from intense storms is flashy and often erosive. The remainder is lost through evapotranspiration. Consequently, the low streamflow period reflects the drainage characteristics of each watershed during the time when the influence of concurrent precipitation is negligible (Hall 1968).

METHODS

Several hundred water samples were collected at the mouths of these watersheds and analyzed over a 3-year period (1970-1972). Most analyses were restricted to chemical and physical characteristics following the techniques described in "Standard Methods" (American Public Health Association 1971). Samples were collected weekly from April through November, and semimonthly during the remainder of the year. Bacterial analyses were made on fewer samples gathered less frequently. Polyethylene containers were used to collect streamflow and precipitation samples for chemical and physical analyses. Sterile, nontoxic, plastic bags were used to sample for bacterial analyses.

Nonfiltered water samples were analyzed for pH, specific conductance, and total alkalinity. Filtered samples were analyzed for calcium, magnesium, sodium, potassium, ortho-phosphate, and nitrate. Dissolved solids were calculated as a product of specific conductance times 0.78, an empirical formula. Suspended sediment was measured gravimetrically.

Bacterial examinations included total coliform, fecal coliform, and fecal streptococci counts. A ratio of fecal coliform to fecal streptococci counts (FC/FS) was used to indicate possible sources of any contamination.[2]

A stream-gaging station on Halfway Creek and recording precipitation gages at the head and mouth of Halfway Creek watershed provided data supplementary to this study. Further interpretive information was available from other precipitation gages in Farmington Canyon, streamflow quality data from Chicken Creeks (5 miles southeast of the three studied watersheds), and the chemical characteristics of precipitation samples collected in the Chicken Creek watersheds.

RESULTS AND DISCUSSION

The bacteriological quality of the three streams was measured in 14 to 17 samples from each watershed. The physical and chemical data came from 29 to 110 samples from each stream (table 1).

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[2]The cooperation of Utah State University, particularly George Coltharp and Les Darling, is acknowledged for the bacterial analyses.

Table 1.--Water quality of Halfway, Corduroy, and Whipple Creeks (1970-1972)

Parameter	Units	No. of samples	Minimum	Maximum	Average
		HALFWAY CREEK			
pH	units	110	6.10	7.80	7.13
Conductivity	µmhos	110	83.00	265.00	105.48
Dissolved solids	mg/l	35	25.20	94.30	70.54
Total alkalinity	mg/l	67	20.00	72.00	32.65
Calcium	mg/l	108	4.17	31.25	9.61
Magnesium	mg/l	104	.41	6.75	3.23
Sodium	mg/l	103	.76	16.25	7.38
Potassium	mg/l	59	.05	6.00	.95
Phosphorus	mg/l	53	.00	.52	.06
Nitrate	mg/l	31	.12	.65	.34
Sodium adsorption ratio	ratio	103			.54
Suspended sediment	mg/l	106	.10	29.70	7.50
Total coliform	counts/100 ml	17	1	500	61
Fecal coliform	counts/100 ml	17	0	183	12
Fecal streptococcus	counts/100 ml	17	0	500	51
		CORDUROY CREEK			
pH	units	70	5.50	7.80	6.98
Conductivity	µmhos	70	82.00	420.00	109.03
Dissolved solids	mg/l	35	53.30	83.30	68.75
Total alkalinity	mg/l	62	22.00	69.00	31.56
Calcium	mg/l	69	.25	23.50	7.72
Magnesium	mg/l	70	2.04	5.70	3.49
Sodium	mg/l	69	1.55	13.00	6.78
Potassium	mg/l	50	.05	6.00	1.05
Phosphorus	mg/l	53	.00	.63	.07
Nitrate	mg/l	30	.25	.70	.37
Sodium adsorption ratio	ratio	74			.49
Suspended sediment	mg/l	69	.30	16.40	5.55
Total coliform	counts/100 ml	17	2	240	42
Fecal coliform	counts/100 ml	17	0	36	2
Fecal streptococcus	counts/100 ml	16	0	230	31
		WHIPPLE CREEK			
pH	units	94	5.70	8.00	7.11
Conductivity	µmhos	94	53.00	695.00	130.79
Dissolved solids	mg/l	29	44.50	119.00	80.95
Total alkalinity	mg/l	66	22.00	60.00	38.97
Calcium	mg/l	93	1.77	24.00	9.56
Magnesium	mg/l	93	.87	9.00	4.37
Sodium	mg/l	93	.60	13.80	8.11
Potassium	mg/l	55	.05	4.70	1.15
Phosphorus	mg/l	47	.00	.55	.07
Nitrate	mg/l	31	.07	.52	.34
Sodium adsorption ratio	ratio	92			.56
Suspended sediment	mg/l	84	.10	247.80	9.86
Total coliform	counts/100 ml	14	2	570	72
Fecal coliform	counts/100 ml	15	0	158	13
Fecal streptococcus	counts/100 ml	14	0	345	60

Chemical Quality

Most mineral-bearing waters are known to have pH values in a narrow range of pH 6 to 9 and to remain very constant. These streams are no exception; the mean value for all three was pH 7.1 and it fluctuated little throughout the year. Total alkalinity, mainly bicarbonate, contributed about half of the total dissolved solids load. This accounts for the neutral pH.

The combined mineral concentration of calcium, magnesium, sodium, and potassium made up 30 percent of the dissolved solids. Even the maximum contents of all ions measured were well within permissible limits for drinking water (Todd 1970).

The nitrate content of runoff from these watersheds is reasonably constant and quite low. Mean nitrate levels of each of these streams were almost equal, averaging 0.35 mg/1. Again, even the maximum concentrations were 60 times lower than the recommended maximum limits for drinking water (Todd 1970).

Interesting relations concerning nitrate-nitrogen and local stream conditions can be shown with supplementary data. The rapid flowing, "bubbling brook" type stream, represented by Halfway, Corduroy, and Whipple Creeks was six-fold higher in nitrate concentration than the slow and placid Chicken Creeks. Chicken Creeks lost nitrate from their sources to their mouths; it apparently was removed by aquatic plants growing in beaver ponds. Nitrate concentration in precipitation falling on the Chicken Creek watersheds usually was greater than that found in the streams.

Ortho-phosphorus phosphate concentration was generally less than 0.10 mg/1. Most natural waters contain relatively low levels of phosphorus in the soluble state.

The quality of these waters for irrigation uses is indicated by the sodium adsorption ratio (SAR) and specific conductance values. Mean SAR values were less than 1.0 milliequivalent per liter for all streams. Conductance was only one-fifth the maximum level recommended for irrigation water. Utilizing both criteria, these streams are in the excellent class, having both low salinity and low sodium hazard (Thorne and Thorne 1951).

Physical Quality

Generally, suspended sediment contents were extremely low. Large quantities are frequently produced by summer storms flushing out the stream channels; but these stormflows comprise a negligible part of the annual water yield. Suspended sediment also increases with the spring runoff, but drops off sharply when this flow recedes. Again, this is apparently a flushing action, removing an accumulation of material from the stream banks. Organic material is prevalent in the suspended sediment, accounting for about 10 percent of the total. The greater suspended sediment load in Whipple Creek, especially during high flows, possibly can be attributed to erosion from the road at the upper border of this watershed.

Bacteriological Quality

Several factors appear to affect the number of bacteria in the streams. These, in turn, resulted in a wide range of values (0 to 500 counts per 100 ml) in the samples. The counts were usually low, approximately 50 counts per 100 ml, and these declined to nearly zero during the winter and spring seasons when the watersheds were completely covered with snow.

A single storm (3.16 inches rainfall in 8 hours) in August 1971 produced high streamflow with very high bacterial counts. In this stormflow the fecal streptococci counts were 500, 230, and 345 per 100 ml from Halfway, Corduroy, and Whipple Creeks, respectively. Fecal coliform counts also were very high. Before and after this storm the fecal coliform counts were at or near zero. Accumulated bacteria-laden material was apparently flushed down the streams. Because fecal coliforms, generally, do not multiply outside the intestines of warmblooded animals, and therefore have short life spans, the high densities of fecal coliforms are indicative of relatively recent pollution. The FC/FS ratios for each stream during this stormflow were less than one, indicating a nonhuman source.

CONCLUSIONS

Water quality from these relatively undisturbed watersheds is extremely good. It is excellent for irrigation. However, the presence of fecal bacteria during much of the year would make it necessary to treat this water to make it potable. Minimal chlorination probably would suffice.

The chemical and physical qualities of these streams, especially the contents of dissolved substances, are related to the climatic and geologic characteristics of the area and indicate possible minimum levels that can be expected for such streams. Nitrate and bacteria contents reflect localized stream conditions that could be important in proper watershed management.

All parameters measured, except suspended solids, appear to reflect similar conditions on all three watersheds. The contour trenching and the road appear to have some influence on suspended solids, with the road through the Whipple Creek drainage possibly increasing sediment production the most. It is just as likely, however, that natural erosion rates are higher in the Whipple Creek than in the Corduroy Creek watershed.

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Research Note INT-187

November 1974

APPRAISING FOREST FUELS: A CONCEPT

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ABSTRACT

Management of our wildland resources requires knowledge of the vegetative load or fuels in the forest. This paper defines the elements making up fuel appraisal and offers a concept for appraising fuels based on current information. An example is presented utilizing data for inland Douglas-fir (Pseudotsuga menziesii).

OXFORD: 431.2:431:432.16

KEYWORDS: fuel appraisal, forest fuels, fire hazard

KNOWLEDGE REQUIREMENTS

To develop plans for fuel or fire management, we must know how to characterize, inventory, and appraise fuels. Countryman (1969) stated that we must regard vegetation as fire areas--as a fuel--and learn to evaluate it in terms that relate to fire behavior. Countryman (1969), Wilson and Dell (1971), and Dodge (1972) are a few of the many researchers who have noted that we cannot really control the weather or shape the topography, but we can and do influence the quantity and character of wildland fuel. Therefore, we must learn to assess wildland vegetation as fuel and appraise potential fire behavior in terms that are meaningful to wildland management personnel. Research on fuel characterization, inventory, and appraisal should be directed toward this objective.

These descriptions of fuels include evaluations of fire behavior characteristics in given fuel situations that indicate the ability of a fire to meet a given objective

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[1]Author is Project Leader, Fuel Science research work unit, stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

or the probability of the fire exceeding a certain level of tolerable activity. Several frames of reference must be used:

1. Situations that relate to short-term change (i.e., the potential as the fire season progresses).

2. Situations that relate to long-term change (i.e., the hazard associated with stand age and successional changes).

3. Situations resulting from interferences with the normal processes of the ecosystems (i.e., what is the fire potential and fuel hazard consequences of a given management action?).

Fire research findings must be combined with other research fields to understand the formation and life history of fuels, fire potential changes, consequences of fire occurrence, and formation of new fuels after a fire. The fuel generation on a unit is the net result of producers and decomposers within the ecosystem and the alterations that man imposes.

FUEL CHARACTERIZATION

The basic data needed to develop a comprehensive understanding of fuel characteristics can come from many published sources: range habitat, silviculture, watershed, wildlife habitat, and timber management. One major aspect of fuel characterization relates to the intrinsic biological and physical properties of a vegetative type. The size class distribution of branchwood for trees and brush is an example. Other examples include the mean size within a size class, the weight distribution of foliage and branchwood, and the fuel load for grasses and brush as related to percent cover and number of stems per acre.

Another major aspect is the growth response of the species or timber type to site and climate in which it exists. This aspect must consider how proportions of live and dead material change with time, but such information is not available. Species response to site and age in tree height, crown weight, d.b.h., and other physical properties has to be established. If fire spread is to be mathematically modeled, then values for fuel density, heat content, and mineral content must be determined. Once determined, these functional relationships can become part of a data source library that can be used to quantify measurements made during the fuel inventory or to model fire behavior.

FUEL INVENTORY

Nationwide, we have only general knowledge of fuels. Knowing fuel quantity and character on a regional basis requires that fuels be inventoried regionally. These inventories would utilize the relationships determined during the fuel characterization process and the most efficient measuring techniques. Then we can have quantitative fuel and vegetation information for interpretation. Interpretation will have to incorporate (1) experienced judgment; (2) comparison to referenced fuel and vegetation; and (3) mathematical models of fire phenomena. An experienced fire manager may be able to look at fuel load and species type and predict fire behavior. Another manager may require mathematical modeling to determine what the behavior may be. The intent is to provide tools that will assist the manager at whatever level he desires.

Before adopting inventory procedures, it is necessary to thoroughly understand the modeling needs in addition to recognizing the requirements and limitations of subjective or comparative interpretation. This demands a new perspective on present-day resource inventory, particularly the need to include dead vegetative material in the inventory. Brown (1971) directed his work toward this need and showed that fuel inventory procedures are compatible with timber and range inventories. Inventory procedures are being used for fuels in the Rocky Mountain area on several National Forests and for the White Cap

Wilderness Fire Management Study in the Selway-Bitterroot Wilderness area (Aldrich and Mutch 1971). These inventory procedures indicate the tons per acre of dead vegetation by size classes, the tons per acre of standing living vegetation by size class, the percent cover of rotten wood, number of trees and dead snags per acre, stand height, tree age, and several other items.

FUEL APPRAISAL

During appraisal, the information on fuel characterization is merged with field inventory data to provide the land manager with an estimate of fuels within a stand. The manager makes estimates of the fire potential or can utilize mathematical models to describe the various fire potentialities of a site. Much thought must go into deciding fire potentials that should be included in fuel appraisal. Although some fuel appraisal has been provided with the National Fire-Danger Rating System (NFDRS) and its broad fuel models, we need to extend our capabilities. At the present time there may be as many elements of fuel appraisal as there are individuals assessing fire hazards. One of the greatest challenges existing in development of a fuel appraisal system is adequately describing the fire hazard. Elements to be considered would include the following:

1. *Rate of spread*: Expressed in a standard spread rate such as chains-per-hour or is divided by the maximum spread rate (as in the NFDRS).

2. *Rate-of-area growth*: Expressed as perimeter length or as acres-per-hour, growth rate would assist in determining the type and amount of suppression forces needed. A reference size such as 10 acres at the end of the first hour could be the relative measure to indicate the speed of attack needed.

3. *Fire intensity*: This element reflects the difficulty of direct attack and may be keyed to the effectiveness of various indirect attack methods. The energy release rate may be referenced to some energy level associated with the onset of conflagration behavior. Flame length can be an effective measure, particularly when compared to some basic standard such as the average man's height. This allows relating to an element of personal danger.

4. *Crowning potential*: The capability of ground fuels to generate flames high enough to reach the tree crown may be equated to the distance to the crown base. Ladder fuels and dead branchwood in the crown are recognized as factors that affect the probability of crowning. In addition to measuring crowning potential, it may be possible to expand fuel appraisal to include assessment of scorching.

5. *Firebrand potential*: This would provide an estimate of a fire's capability to produce and cast burning embers into the convection column and the ambient wind's ability to carry the embers. In order to determine if any of the embers will reach the ground still burning, we need to estimate gas velocity and inventory the fuels well enough to identify firebrand material by size class and weight. Considerable research is needed to develop the necessary base information.

6. *Spot fire potential*: This factor would be similar to the ignition component of the NFDRS but the fuel most likely to be ignited must be identified. This element of fuel appraisal would compare the time required to ignite fine fuels with the burning time of the most probable firebrand. Additional research will be necessary to determine the accuracies required.

7. *Fire persistence*: This element would indicate the potential mopup problem and the probability of holdover fire. The percentage of area covered with punky and rotten material and rate of spread by glowing combustion may be developed to represent the time required for the fire to reach a more flammable fuel. This hazard will require extensive research to provide an adequate index of the mopup job or the problems with fires

that are dormant for hours or days and, in some cases, weeks. Additional study of the latent stage of a fire (the probability of holdover fires occurring) needs to be done (Taylor 1969).

These factors can be useful elements within a fuel appraisal system; however, each element must be considered on an individual basis related to the site. After individual judgment, a merging of the fuel appraisal factors must be made by the manager to obtain the total fire problem of the site. These fire hazard elements are only some of the possibilities. Suggestions on other hazard elements that should be considered are invited.

RELATED CONSIDERATIONS

A fuel appraisal system must accommodate the weather variations across the country so objective comparisons can be made of similar fuel situations in different weather regimes. Fire weather is a variable we cannot control. It also is one of the dominant factors of the fire potential for any given day. The publication "Fire Weather" (Schroeder and Buck 1970) provides a general view of the United States by fire climate regions and points out that fire-danger rating integrates the weather elements with other factors affecting fire potential. The NFDRS (Deeming and others 1972) builds the danger rating indexes from fire-danger station readings of temperature, cloud cover, precipitation, relative humidity, and windspeed. NFDRS ratings are relative and not absolute. The fuel models developed for the NFDRS were general models to reflect the trends in expected behavior of a potential fire. A fuel appraisal system will be a supplement to the NFDRS by quantifying fuels that exist upon a given unit of land. Changes in the amount of fuel available to the fire due to weather changes should be recognized in the appraisal system.

The capability of firefighting forces to maneuver on the fireline and the fire's resistance to control efforts must be considered in fuel and fire management plans. Because many suppression techniques are available and rates for fireline building vary, resistance to control may need to be assessed separately from fuel appraisal even though fuel inventory information is used. Storey (1969) noted that the assumed production rates for a given type of fireline construction were found to vary widely among the Forest Service Regions and the differences could not be explained on the basis of different soil, fuel type, or other conditions. In addition, he noted that productivity data for various types of firefighting forces are available for only hand crews and bulldozers although nine forms of forces were recognized.

Guides are only as good as the conceptual design and the input data. If we are going to use national fire-danger rating and desire national fuel appraisal, it also makes sense that we have a measure for national fireline productivity. I anticipate that future use of computer techniques and mathematical modeling for fire-danger rating, fuel appraisal, and fireline productivity will not be used for dispatching, but that experienced judgment will be the best and fastest way to estimate tradeoffs under actual situations. However, planning on a day-to-day basis or a year-to-year basis can make use of these systems if they are based on objective, quantitative data.

A CONCEPTUAL APPROACH

In forest research, we now have enough data to begin fuel appraisal. The concepts that have been expressed in this paper can be illustrated in an example with inland Douglas-fir (*Pseudotsuga menziesii*) represented by site index of 60 at 50 years of age. The fuels being appraised will be those less than 2 inches in diameter in the tree canopy.

The following equations were assembled to allow assessing the fuel changes in the specified fuel type over time.

$$H_T = 91.57[1 - 1.153 \exp^{-0.0255A}]^{1.0608} = \text{tree height, ft.}$$

where

A = age, years

$DBH = \exp[1.317 \ln(H_T) - 2.688]$ = diameter at breast height, inches. The above are after the work of Brickell (1968).

$$h = 4.0 + 2.60\ DBH = \text{crown length, ft.}$$

$$W_c = \frac{[(DBH)(h)]^{1.0108}}{3.811} = \text{crown weight/tree, lb/tree, ovendry weight.}$$

These equations were determined by Fahnestock (1960) or were modified by him after Storey and others (1955).

$$C_w = 5.031 + 1.423(DBH) = \text{maximum crown width, ft.}$$

This equation is cited by Bella (1971), after Newnham,[2] and may represent coastal Douglas-fir more accurately than inland Douglas-fir.

The work by Storey provided total crown weight and the portion that is in foliage and branchwood. Consolidating these data with Fahnestock's provides the mean size within each size class and the portion of the total fuel load in each size class.

The characteristic distribution of foliage and branchwood by size class is shown in figure 1 and was acquired through the works of Fahnestock (1960) and Storey and

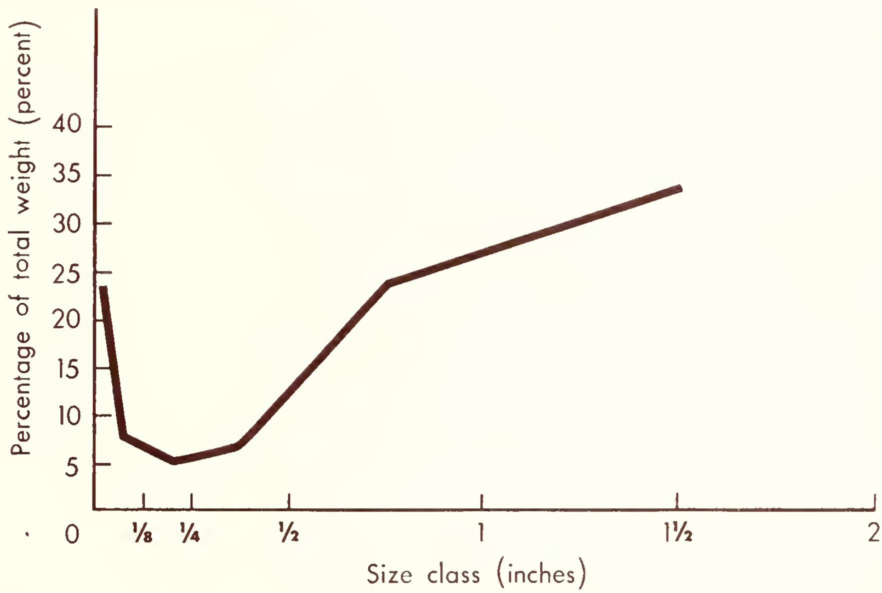

Figure 1.--Percentage of total crown weight by size class for material under 2 inches diameter (inland Douglas-fir).

[2] R. M. Newnham, Unpublished thesis, University of British Columbia. 1964.

others (1955). Other works, including theirs, show that a number of timber types have a similar characteristic. Data collected on Engelmann spruce (*Picea engelmannii*), grand fir (*Abies grandis*), Douglas-fir, and western hemlock (*Tsuga heterophylla*) indicate that these timber types have general characteristics of distribution that could be described by one equation. This characterization of the distribution of fuel by size is needed for slash considerations or crown fire estimates.

Using the data and equations described we can calculate the number of even-aged trees on a site, the total crown weight or unit area fuel load, and the d.b.h. at any age. An assumption (any number of assumptions are possible) is made that this stand is being managed or is adjusting itself to maximum utilization of space and light and that the stand is always at 100-percent crown closure. With these assumptions and the equations cited above, stand properties are illustrated in figure 2. The number of trees per acre is determined by knowing crown width, calculating the area for each tree crown, and determining the number of tree crowns per acre. This information, then, with the crown weight per tree, gives the tons per acre of material under 2 inches diameter.

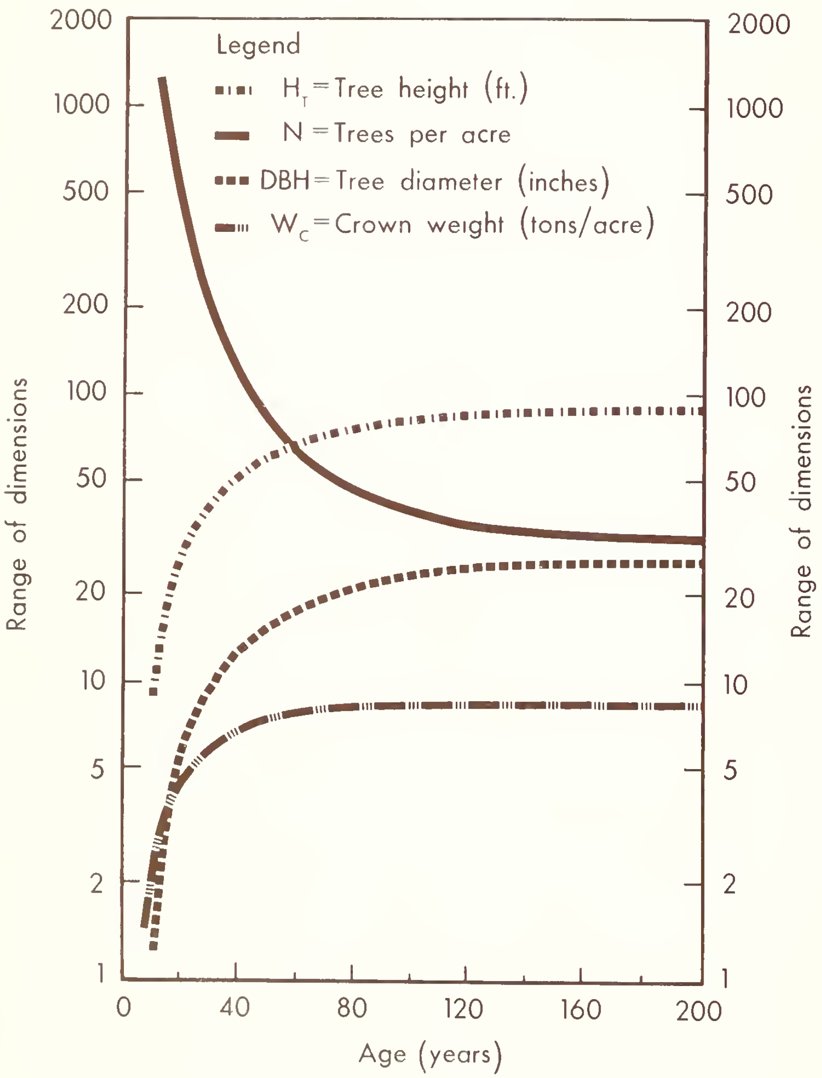

Figure 2.--Inland Douglas-fir stand physical properties change with time on a site index of 60 at age 50 years. Site equations and curves by Brickell (1968) were utilized.

Figure 2 shows that in a crop of trees the amount of dead material either on the ground or standing changes with time. In this example, the number of trees is continually decreasing with age, which suggests that a number of trees are dying in each time interval. These trees and their crown load contribute to the fuel load that is underneath this stand. This fuel is estimated by first determining the number of trees lost per acre between two age classes. Second, this number of trees per acre is multiplied by the crown weight per tree to obtain the fuel load gain per acre for the time period used. To be realistic, the decay rate of this material must be estimated.

Decay rates have been determined for downed foliage and branchwood. A simplifying general concept is that this decay rate, like many other natural rates, is exponential, as shown in the following equation:

$$W = W_0 \exp\left(\frac{-t}{T}\right) = \text{Tons/acre}$$

where

W_0 = initial fuel load, tons/acre

T = decay constant, years

t = time since start of decay, years.

The work by Childs (1939) on decay of slash in the Douglas-fir region provides an estimate of the decay constant. For Douglas-fir slash and western hemlock, in stands referred to as Douglas-fir type, the decay constant (or time to lose 63 percent of the volume) ranged from 15 to 29 years. In this paper a decay constant of 20 years is used to demonstrate the appraisal technique.

Changes in fuel load were estimated at 10-year intervals, adjusted for decay, and then summed. Dead crown fuel accumulated underneath a Douglas-fir stand is shown in figure 3. Accumulation peaks about 30 years after stand establishment because of the

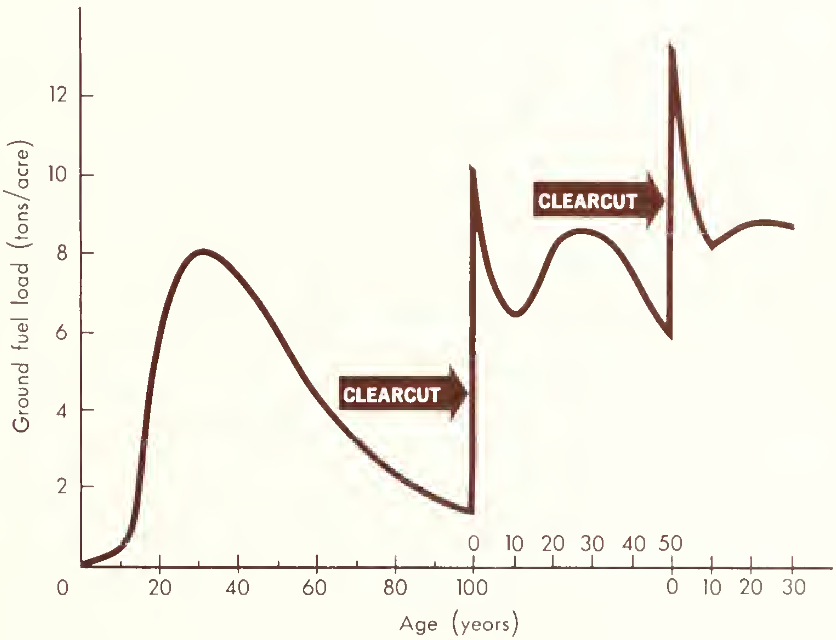

Figure 3.--Changes over time in estimated crown-contributed ground fuels, less than 2 inches in diameter, under an even-aged Douglas-fir stand due to natural thinning or timber harvest.

large change in number of trees per acre between the 20- and 30-year points and the 30- to 40-year points. In addition to knowing the quantity of fuels less than 2 inches in diameter, we also need an estimate of the understory fuel components before we can establish fire behavior or fuel appraisal factors. Estimates of the fuel load, depth, and surface-area-to-volume ratio for ground fuel are given in table 1.

Estimates of surface-area-to-volume ratios and fuel depths were obtained from publications by Brown (1970a,1970b) and Lyon (1971). The data generated through this example can be used as input to fire behavior and flame prediction equations such as generated by Rothermel (1972) and Thomas (1963) and utilized by Brown (1972). Weather conditions were applied as part of the fire spread model inputs. Fuel moisture content was set at 4 percent; average windspeed was set at 8 mi/h, which is slightly higher than the average windspeed during the summer in most of the Western United States (USDC Environmental Science Services Administration 1968).

Fuel appraisal concepts are the results obtained by combining the output of mathematical fire simulations with fuel inventory and research data developed for other fire behavior characteristics. For this example we will consider forward rate of spread, flame length, and flame height as our fuel appraisal factors. To determine the relative hazard, a reference is needed for each factor. Based on Forest Service data for the Western United States, the average forward rate of spread is approximately 15 chains per hour. Divide the calculated forward spread by this factor. For flame length, consider the equating factor as 6 feet (an average man's height), which relates to the personal danger involved in working close to the fireline. For measuring crowning potential, reference flame height against the distance to the base of the live crown. Using the data presented in table 1, the three factors were evaluated. Results, presented in table 2, provide some insights into the effects of cultural treatments, fuels, consequences, and some aspects of fire behavior needing consideration at various periods in the life cycles of the site.

Table 1.--*Estimate of ground fuel properties essential to establishing fuel appraisal factors in a Douglas-fir stand*

Age (years)	Ground fuels	Crown dead fuels[1]	Total fuel	Fuel depth	Average fuel diameter	Average surface-area-to-volume ratio
	- - - -	-*Tons/acre*-	- - - -	*Feet*	*Inches*	*Ft^2/ft^3*
10	1.0	0.3	1.3	1.5	0.027	1,750
30	.5	8.0	8.5	.5	.120	400
50	.5	5.8	6.3	.4	.137	350
100	.2	9.9	10.1	2.5	.077	622
120	1.5	8.0	9.5	1.8	.137	350
140	.2	7.3	7.5	1.5	.137	350
150	.2	12.8	13.0	3.0	.077	622

[1]Material is assumed to fall to the ground in the last 10 years.

Table 2.--*Fuel appraisal factors for a Douglas-fir site and timber stand at various ages. Factors greater than 1.0 represent an increase in hazard whenever wind reaches 8 mi/h and fuel moisture reaches 4 percent*

Age (years)	Rate of spread factor	Flame length (intensity) factor	Flame height (crowning) factor
10	21.6	4.2	6.4
30	1.4	6.5	1.3
50	1.0	4.1	.6
100/0[1]	12.1	27.7	[2] 5.8/--
120	4.9	12.9	4.6
140	4.1	9.1	1.7
150/0[3]	14.4	39.4	10.3/--

[1]Assumes clearcut at 100 years, followed by regeneration.

[2]Once clearcut, there would be no crown base for flame height to reach. Remaining tree crowns would be scorched or burned out.

[3]Assumes regeneration cut at age 50.

DISCUSSION

The fuel factors in table 2 point out some of the considerations we can make as we plan our management activities. For instance, at 10 years of age fire spread will be high due to herbaceous material (table 1). The flame will not be very intense but it will be high enough to scorch regeneration. At 30 and 50 years of age, both the spread factor and flame height factor have decreased. The flame height factor has decreased because fuel buildup has been too slow to allow flame height to reach the base of the crown. However, the flame length factor peaks at about 30 years when there is a maximum amount of fuel on the ground. The effect of clearcutting the stand is shown at the 100-year point in time. The flame length factor has increased to a high value that reflects the difficulty of fighting fire close to the fireline in slash. At the second cutting in year 50 of the second cycle we can see that spread is significant, as is flame length factor. Fuel buildup is leading to a more and more difficult fire situation. In addition, the flame height factor shows that if we leave seed trees or make a shelterwood cut, flame height will be as much as 10 times the height to the base of the crown, which will result in crown scorch and individual crowning of trees.

SUMMARY

I have presented a general concept for quantifying fuel appraisal that will provide the land manager another decisionmaking tool. I recognize that considerable effort is needed to pull together existing data, identify the missing information, conduct studies, and develop appraisal approaches that will be meaningful to fieldmen. Nevertheless, I think the concept discussed can provide a better base for making plans and decisions for fuels and fire management than we have had in the past. We now need to pool existing capabilities and knowledge to refine and develop a fuel appraisal system that will be universally useful.

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USDA Forest Service
Research Note INT-188

January 1975

COMPARING ACTUAL TIMBER GROWTH WITH POTENTIAL: SOME IMPLICATIONS FOR MONTANA

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ABSTRACT

Comparing actual timber growth (production) with potential can serve as a benchmark for monitoring management efforts or direction. In 1970, the estimated gross growth on Montana's 16 million acres of forest land classified as commercial for timber production was 607 million cubic feet. Assuming management could have been intensified, especially on the more productive acres, production could have been increased substantially on this area; or, the 1970 level of growth could have been obtained from considerably less area.

OXFORD: 815; 56
KEYWORDS: timber growth, site productivity, wood yield, forest management

Most foresters agree that greater timber production is possible through intensified timber management. Increasing demand for timber production in the face of increasing demand for nontimber use of forest land emphasizes the need to initiate and continue intensive management--prompt regeneration of nonstocked acres and adequate stocking control. Comparing actual growth with potential wood production provides a guide to what might be achieved.

The comparison presented here bases potential production estimates on the "peak" mean increment of wood added annually in fully stocked stands. The comparison also assumes that, under management, trees can be grown through the rotation to the planned harvest time at the peak rate.

Using data from Montana, this report contrasts actual with potential timber production by site productivity classes (USDA Forest Service 1967).

Site productivity class	*Potential wood production*
	ft³/acre/yr
I	165+
II	120-164
III	85-119
IV	50-84
V	20-49

Growth data by productivity classes are available for only a portion of Montana and are for 1970. The data represent about 2.8 million of the 16 million acres of commercial forest land in the State (fig. 1). These 2.8 million acres were producing about 190 million cubic feet of wood in 1970. If the total acreage was devoted to intensive timber production (full and controlled stocking) the 2.8 million acres theoretically could produce nearly 270 million cubic feet per year.

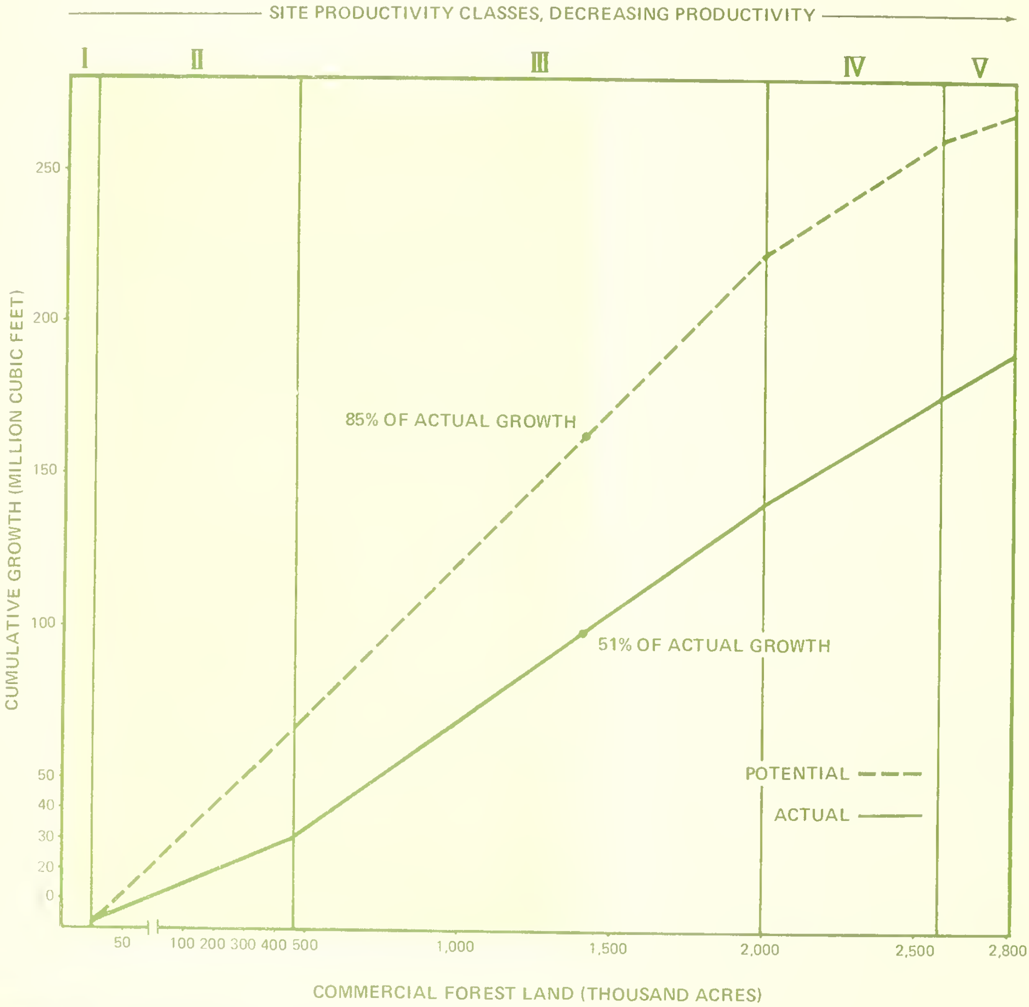

Figure 1.--Estimated actual and potential timber growth on 2.8 million acres of commercial forest land in Montana, 1970. The shaded portion represents the most productive half of the area.

The illustrated comparison of actual and potential growth for the 2.8 million acres suggests that:

1.--The more productive half of the area, about 1.4 million acres, accounted for little more than half of the 2.8-million-acre area's timber growth in 1970.

2.--The more productive half of the area, producing at its potential, might contribute 85 percent of the total area's annual timber growth.

3.--The 2.8-million-acre area's production could be obtained from approximately 1.65 million of the most productive acres if potential could be achieved. For example, if potential productivity could be reached on productivity classes I and II land only, volume would increase almost 37 million cubic feet annually.

4.--Growth on the area could be increased about 80 million cubic feet annually if potential productivity could be achieved on all acres.

* * * * * * * * * * *

In 1970, about 16 million acres of forest land in Montana was classified as commercial timber producing land. The estimated annual gross growth was 607 million cubic feet (Green and Setzer 1974). The estimated potential productivity of this land is 1,165 million cubic feet of wood per year.

Figure 2 depicts estimated actual and potential growth for Montana's commercial forest land. Because growth data by productivity classes are not available for all of Montana, acreages in the site productivity classes for the State (fig. 2) were initially assigned the same current growth per acre as the classes in figure 1. Resulting growth totals for classes were adjusted proportionally by means of the ratio between grand total growth for all classes and the 1970 estimate of current growth for the State. This illustration suggests that:

1.--Current productivity is well below potential productivity.

2.--Timber production could be maintained at present levels on considerably less area, providing these acres were producing at potential.

3.--Timber production might be increased by as much as 92 percent on the 1970 commercial forest land if management could be intensified to the theoretical maximum.

This analysis, though limited to the physical possibilities of wood production, could serve as a benchmark for monitoring management efforts or direction. Of course, other considerations are important. These include (1) the cost and rate of return of achieving potential production; (2) the effects of not managing low-productivity forest land supporting insect-infested or diseased stands; and (3) the necessity of accommodating nontimber use on some commercial timberland.

The comparison confirms opinions expressed by many foresters that intensified timber management on the more productive acres can increase growth to meet present and future needs for wood. It is physically possible to increase wood yields on present commercial forest land, or to produce present yields on fewer acres if prompt regeneration is achieved and stocking control is maintained.

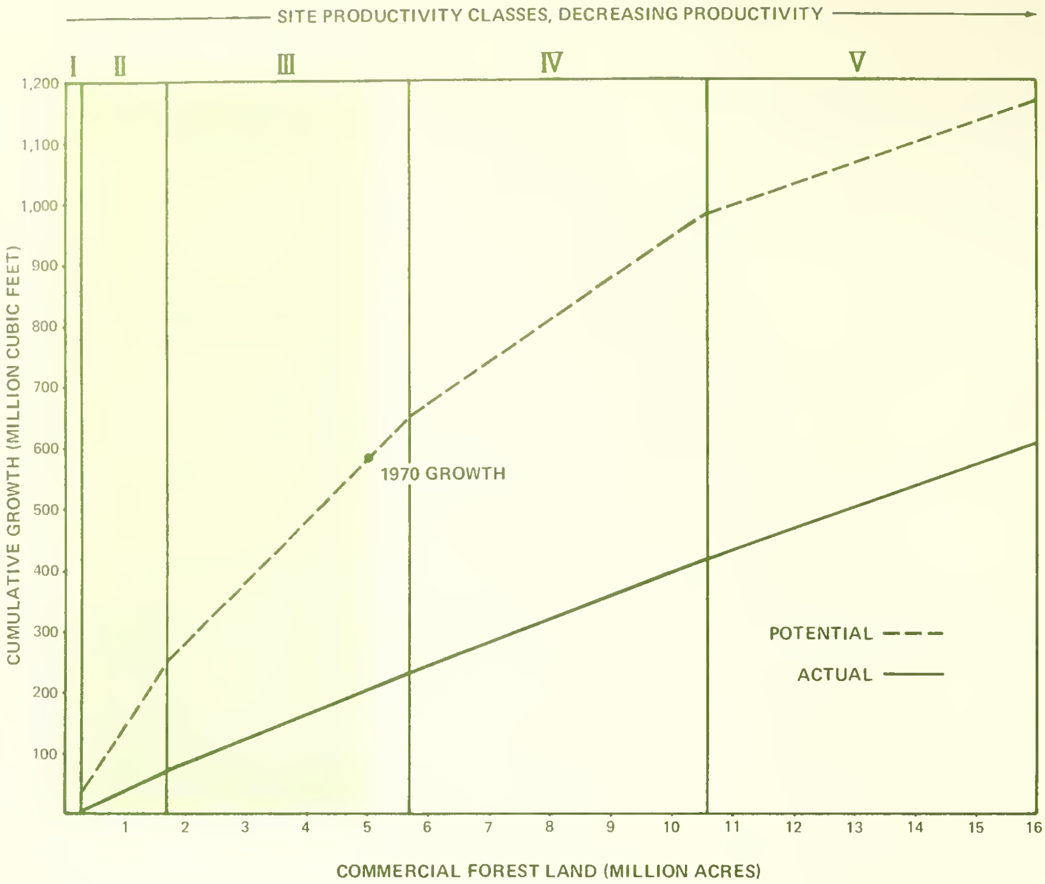

Figure 2.--Estimated actual and potential timber growth on Montana's approximate 16 million acres of commercial forest land. The shaded portion represents the acreage which theoretically could produce 1970's 607 million cubic feet, gross growth.

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USDA FOREST SERVICE RESEARCH NOTE INT-189

CHARACTERISTICS OF DOUGLAS-FIR BEETLE INFESTATION IN NORTHERN IDAHO RESULTING FROM TREATMENT WITH DOUGLURE

G. B. Ringold, P. J. Gravelle, D. Miller,
M. M. Furniss, and M. D. McGregor[1]

ABSTRACT

Nearly 800 mature Douglas-fir trees along logging roads were baited with Douglure at approximately 4-chain intervals. After beetle attack, trees were examined for infestation within 2 chains of 24 baited trees. Nine untreated "spillover" trees were attacked for each treated tree. Beetles failed to produce brood in 56 percent of the attacked trees. Successfully attacked (susceptible) trees were significantly larger and were infested to a significantly greater density and length than were unsuccessfully attacked (resistant) trees. Baited trees were more susceptible to successful attack than were spillover trees. Brood/parent ratios were less than 0.5 in successfully attacked trees in early August. The study indicates that tree size and stand density affect the rate and success of Douglas-fir beetle attack in the vicinity of Douglure treatment.

OXFORD: 453, 414.11

KEYWORDS: Insects, attractants, Douglas-fir beetle, bark beetle, Douglure, aggregating pheromone, forest protection

The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, causes economic damage to Douglas-fir sawtimber in many areas of the West. A recent infestation in the Clearwater River drainage of northern Idaho killed 109 MMbf of timber from 1970 through 1972 (Ciesla and others 1971; McGregor and others 1972; McGregor and others 1974).

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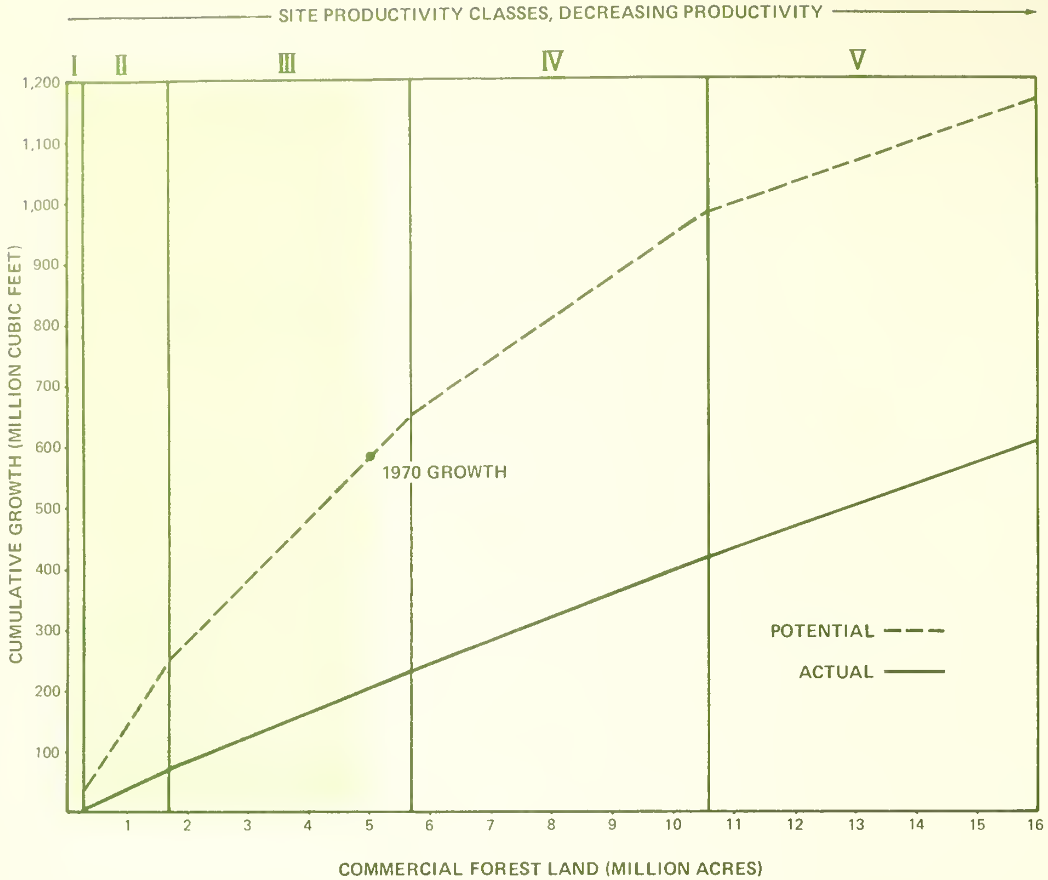

Figure 2.--Estimated actual and potential timber growth on Montana's approximate 16 million acres of commercial forest land. The shaded portion represents the acreage which theoretically could produce 1970's 607 million cubic feet, gross growth.

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U.S. GOVERNMENT PRINTING OFFICE: 1974 _ 677-696 / 52; REGION NO. 8

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USDA FOREST SERVICE RESEARCH NOTE INT-189

CHARACTERISTICS OF DOUGLAS-FIR BEETLE INFESTATION IN NORTHERN IDAHO RESULTING FROM TREATMENT WITH DOUGLURE

G. B. Ringold, P. J. Gravelle, D. Miller,
M. M. Furniss, and M. D. McGregor[1]

ABSTRACT

Nearly 800 mature Douglas-fir trees along logging roads were baited with Douglure at approximately 4-chain intervals. After beetle attack, trees were examined for infestation within 2 chains of 24 baited trees. Nine untreated "spillover" trees were attacked for each treated tree. Beetles failed to produce brood in 56 percent of the attacked trees. Successfully attacked (susceptible) trees were significantly larger and were infested to a significantly greater density and length than were unsuccessfully attacked (resistant) trees. Baited trees were more susceptible to successful attack than were spillover trees. Brood/parent ratios were less than 0.5 in successfully attacked trees in early August. The study indicates that tree size and stand density affect the rate and success of Douglas-fir beetle attack in the vicinity of Douglure treatment.

OXFORD: 453, 414.11

KEYWORDS: Insects, attractants, Douglas-fir beetle, bark beetle, Douglure, aggregating pheromone, forest protection

The Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, causes economic damage to Douglas-fir sawtimber in many areas of the West. A recent infestation in the Clearwater River drainage of northern Idaho killed 109 MMbf of timber from 1970 through 1972 (Ciesla and others 1971; McGregor and others 1972; McGregor and others 1974).

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 January 1975

As part of a coordinated salvage program in cooperation with the Northern Rockies Forest Pest Action Council, the Douglas-fir beetle attractant, Douglure,[2] was tested in the North Fork Clearwater River drainage in northern Idaho by Potlatch Corporation for its utility in concentrating beetles in accessible trees to be removed by logging. Treatment with Douglure--a mixture of frontalin, α-pinene, and camphene--has been shown to result in beetles attacking both baited and nearby "spillover" trees (Knopf and Pitman 1972; Pitman 1973). These studies have resulted in proposals of a strategy of concentrating or "trapping out" beetle populations with aggregating pheromone chemicals such as Douglure.

Baiting was more intense in the Buck and Doe Creek drainages than in any other reported project. We decided to take advantage of this high baiting level to document the proportions of successfully and unsuccessfully attacked trees. Such information would aid planning of a test of a "confusion" strategy involving areawide application of aggregating pheromones such as Douglure to disrupt normal aggregation on host trees. A particular concentration and spacing of the pheromone might subject each Douglas-fir in the treated forest to equal risk of attack, thus dispersing the beetle population to the extent that most trees would survive the resulting low density of attack. Previous study has shown that unsuccessfully attacked trees contained 3.4 galleries per ft^2 compared to 10.9 per ft^2 in successfully attacked trees.[3]

METHODS

From May 5 through 10, 1973, nearly 800 live Douglas-fir near logging roads were treated at approximately 4-chain intervals with Douglure in Buck and Doe Creek drainages (fig. 1), 16 miles northeast of Orofino, Idaho. The largest trees were baited. The treatments were as per Pitman (1973), except that two instead of four Douglure-charged polyethylene containers were attached to each baited tree at breast height. The removable caps on some containers dissolved, so it is possible that the rate of diffusion of Douglure may have exceeded that in earlier reported experiments.

From July 30 through August 3, 1973, we randomly selected 24 sample plots within the resulting infestation. We measured diameter at breast height and estimated the infested height, based on frass and exuded resin, for the treated tree at the center of each plot. Identical data were obtained for spillover trees within the following distances from treated trees: 0 to one-half, one-half to 1, and 1 to 2 chains. Attack success was also determined for all standing trees on all plots by chopping into the bark 8 to 12 ft above ground and examining egg galleries in the phloem. Based on degree of resinosis, abundance of brood, and condition of the phloem, trees were rated (1) successfully attacked (susceptible), (2) intermediate, or (3) unsuccessfully attacked (resistant). We also determined the basal area of each plot with a 25 basal area factor prism (Dilworth and Bell 1973).

On 13 of the plots we felled the baited tree and a randomly selected spillover tree in each of the three distance classes if one occurred there. Then we measured the exact infested height and located three 1-ft^2 sample areas at one-fourth, one-half, and

[2]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

[3]M. M. Furniss. Observations on resistance and susceptibility to Douglas-fir beetles. Paper presented at Second North American Forest Biology Workshop, Oreg. State Univ., July 31-Aug. 3, 1972.

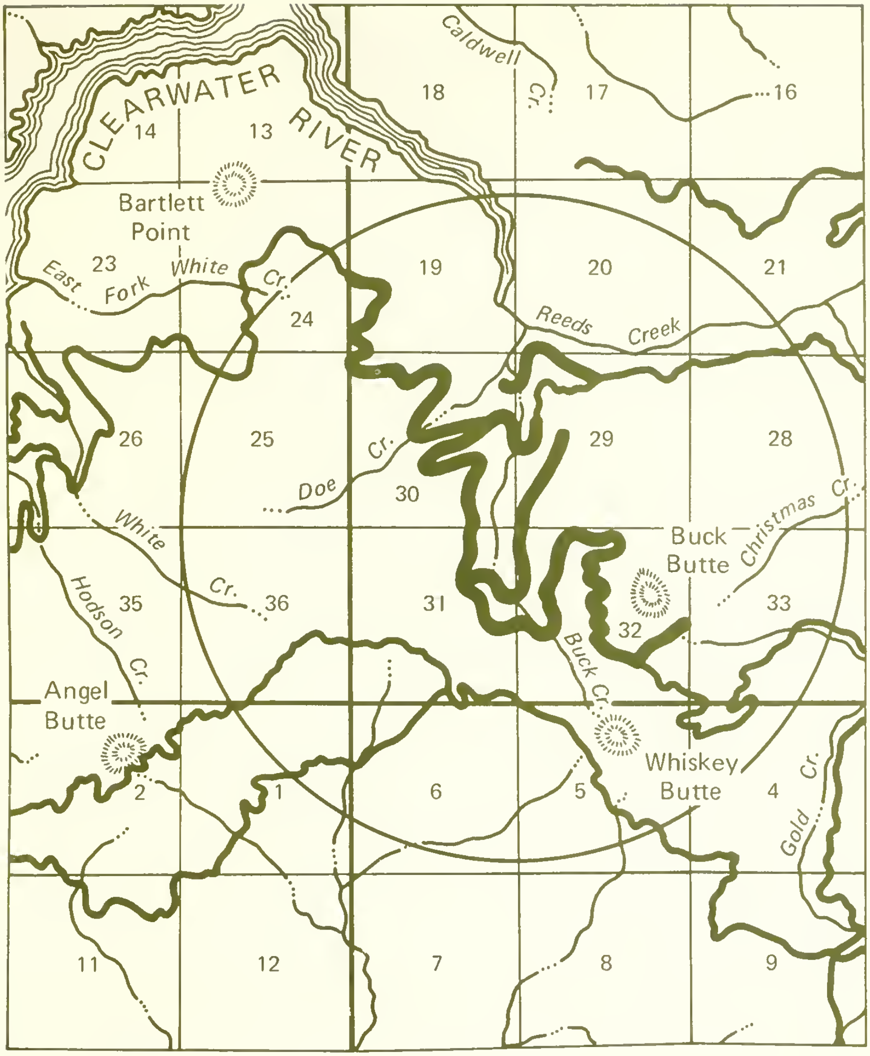

Figure 1.--Roads along which trees were baited with Douglure.

three-fourths the distance from the stump to the uppermost attack area. From these samples we determined the number of attacks, length of egg galleries, and numbers of parent beetles present (fig. 2). On a 6- by 6-inch subsample we counted the number of live brood by stage. The smaller sample was used because brood density was often greater than the variables measured on the larger sample.

The significance of differences of sample averages was determined from treated and spillover trees by distance class. Infestation characteristics (infested height, brood density, and gallery length) were regressed stepwise on tree characteristics and distance from baited tree to determine significant sources of variation and their relative contribution toward variation in the dependent variable.

Figure 2.--Determination of number of Douglas-fir beetle galleries on bark sample from unsuccessfully attacked "spillover" tree.

RESULTS AND DISCUSSION

The effectiveness of Douglure as an attractant was again demonstrated. Treatment of roadside trees at ca. 4-chain intervals generated an estimated 8,000 attacked trees, 89 percent of which were spillovers. Fifty-six percent of the trees were attacked unsuccessfully but this rate did not appear to be greater than was observed elsewhere in the untreated areas.

Tree Characteristics by Success of Attack and Distance From Treatment

We found that our initial classification of "Intermediate" susceptibility of standing trees was not always consistent with brood success on bark samples after trees were felled. Where broods were found, we combined "Intermediate" with the "Susceptible" class.

Generally, the susceptible trees were significantly larger, and were infested to a significantly greater height than were the resistant trees (table 1). Differences tended to be less as distance from the baited tree increased, but these differences were not significant except in the case of infested height in susceptible trees.

Table 1.--*Average tree measurements by success of attack and distance from Douglure treated trees on 13 plots*

Distance class	Trees measured	D.b.h.	Age	Tree height	Infested height
		Inches	*Years*	*Feet*	*Feet*
		RESISTANT TREES			
Plot center (Baited tree)	7	[1] 17.4a	121a	110a	30a
<1/2 chain	4	17.3a	142a	108a	24a
1/2-1 chain	8	16.5a	125a	116a	32a
>1 chain	4	16.0a	119a	107a	28a
		SUSCEPTIBLE TREES			
Plot center (Baited tree)	6	23.3b	147a	118a	66b
<1/2 chain	5	20.7b	137a	114a	45c
1/2-1 chain	6	21.2b	142a	114a	59d
>1 chain	5	20.4b	118a	106a	48e

[1] Means with a common alphabetical suffix do not differ significantly; those having different suffixes differ significantly at the 0.05 level of probability.

Density of Attacks and Brood by Distance From Treatment

Baited and susceptible trees were attacked significantly more densely than were spillover and resistant trees (table 2). Baited trees were successfully attacked at a significantly higher rate than were spillover trees (table 3). All but two of the baited trees were attacked. One was in a cutover area with no other Douglas-fir within 2 chains, the other was in a stand containing only one other Douglas-fir within 2 chains.

We interpret the difference in density and success of attack to the effectiveness of Douglure which evidently aggregated more beetles on the baited trees, and to baited trees being generally greater size (table 1). A previous study (footnote 3) showed that successfully attacked trees were significantly larger than unsuccessfully attacked trees in naturally attacked tree groups.

The brood/parent ratios in successfully attacked trees were low (table 2) at the time of sampling (July 30-August 3). However, a relatively low (0.8) ratio was also found in an independent survey of naturally attacked trees elsewhere in the Clearwater drainage in September (McGregor and others 1974). These low ratios may be due to the very dry, warm summer; other natural factors involved in the declining phase of the outbreak; or, in the case of Buck and Doe Creeks, to use of Douglure on trees not selected naturally by beetles. Whatever the case, brood ratios less than 1.0 indicate a declining population unless compensated for by reemergence of parents and establishment of a second brood.

Table 2.--*Density of Douglas-fir beetle attacks, parents, and brood/parent ratios by distance from treatment on 13 Douglure plots*

Distance class	Number of observations	Attacks	Live brood	Parents on sample	Brood/parent ratio[1]
			Number per ft²		
		RESISTANT TREES			
Plot center (Baited tree)	7	9.2	0	0.17	0
<1/2 chain	4	5.1	0	.19	0
1/2-1 chain	8	5.3	0	.03	0
>1/2 chain	4	3.0	0	0	0
		SUSCEPTIBLE TREES			
Plot center (Baited tree)	6	11.9	5.9	0.30	0.25
<1/2 chain	5	7.5	2.9	.56	.19
1/2-1 chain	6	8.5	8.1	.37	.48
>1/2 chain	5	8.7	4.9	.29	.28

[1]Number live brood ÷ 2(number of attacks).

Table 3.--*Success of attacks by distance from baited trees on 24 Douglure-treated plots*

Distance class	Attack category		
	Successful	Intermediate	Unsuccessful
	- - - - - - - *Percent of total* - - - - - - - -		
Plot center (baited tree)	67	25	8
<1/2 chain	45	6	49
1/2-1 chain	34	5	61
>1 chain	45	5	51

Significant Sources of Variation in Baited and Spillover Trees

Table 4 lists significant sources of variation between bark sample data and tree characteristics in baited and spillover trees.

Table 4.--*Results of multiple regression of attack characteristics and tree characteristics for 24 Douglure-treated plots*

Factor	Variable	Significance[1] Baited	Spillover
Infested height	D.b.h.	N.S.	0.001
	Brood density	0.001	.001
	Gallery length	N.S.	N.S.
	Distance	N.S.	N.S.
	Diameter growth (D.b.h./age)	N.S.	N.S.
	Height growth (Height/age)	N.S.	N.S.
	Form (D.b.h./height)	N.S.	N.S.
	Age	N.S.	N.S.
Live brood per square foot	Form	N.S.	.001
	Gallery length	N.S.	.1
	D.b.h.	.005	.1
	Height	N.S.	N.S.
	Distance	N.S.	N.S.
	Age	N.S.	N.S.
	Diameter growth	N.S.	N.S.
	Height growth	N.S.	N.S.
Total gallery length per square foot	Attack density	N.S.	.001
	Form	.001	.001
	Brood density	N.S.	.025
	Diameter growth	N.S.	N.S.
	Height growth	N.S.	N.S.
	Distance	N.S.	N.S.
	Age	N.S.	N.S.
	Height	.01	N.S.

[1]N.S. = no statistical significance.

In the baited trees the height of infestation was not significantly related to tree diameter nor was the density of the galleries significantly related to length of galleries intercepted by samples. Also, in the baited trees, the average length of the galleries per square foot had no significant relation to density of live brood, but the taller trees produced more inches of galleries per square foot.

In spillover trees, the height of the infestation was directly related to tree diameter, and density of attacks was directly related to gallery length and brood density. However, there was no significant relationship to gallery length and tree height in spillover trees.

Diameter growth, height growth, tree age, and distance from the baited tree showed no significant relationship to infested height, brood production, or gallery length in either baited or spillover trees.

Stand Composition and Basal Area in Relation to Infestation

Results of our sampling of stand composition and basal area on 24 plots are shown in table 5. Statistical analysis of basal area and (1) proportion of trees that were attacked, (2) percent of successful attacks, and (3) brood density disclosed no significant relationships. Perhaps lack of significance may have been due to an omission of smaller diameter trees with the 25-factor prism method, but we can only speculate on that.

Table 5.--*Basal area and proportion of tree species on 24 randomly selected Douglure treated plots*

Species	Basal area/acre	Percentage
	Ft^2	
Douglas-fir	83.3	38
Cedar	63.5	29
Grand fir	36.4	17
Larch	21.9	10
Ponderosa pine	9.4	4
White pine	4.2	2
Total	218.7	100

CONCLUSIONS AND RECOMMENDATIONS

We noted that the number of attacked trees surrounding a baited tree increased in proportion to the surrounding area out to 1 chain (fig. 3), decreasing thereafter. This relationship provides limited insight into the spacing relationship of Douglure and resulting attack in the surrounding stand. Evidently, at the existing population level and Douglure concentration employed, spacing would have to be less than 4 chains if all intervening Douglas-fir were to be subjected to attack.

The original objectives and design of the baiting project did not provide for evaluating the overall effect of baiting on the beetle population and damage. Nonetheless, the attacked trees were attacked by far more beetles than the attackers produced, as shown by exceptionally low brood/parent ratios.

In commercial forests, application of aggregating pheromones such as Douglure may be combined with logging of infested trees. However, the method needs further testing and development to demonstrate its efficacy in suppressing beetle damage. Meanwhile, if inducing a high rate of successful attack is the objective of a Douglure treatment, our study confirms that larger trees in rather dense stands of Douglas-fir are more susceptible to attack.

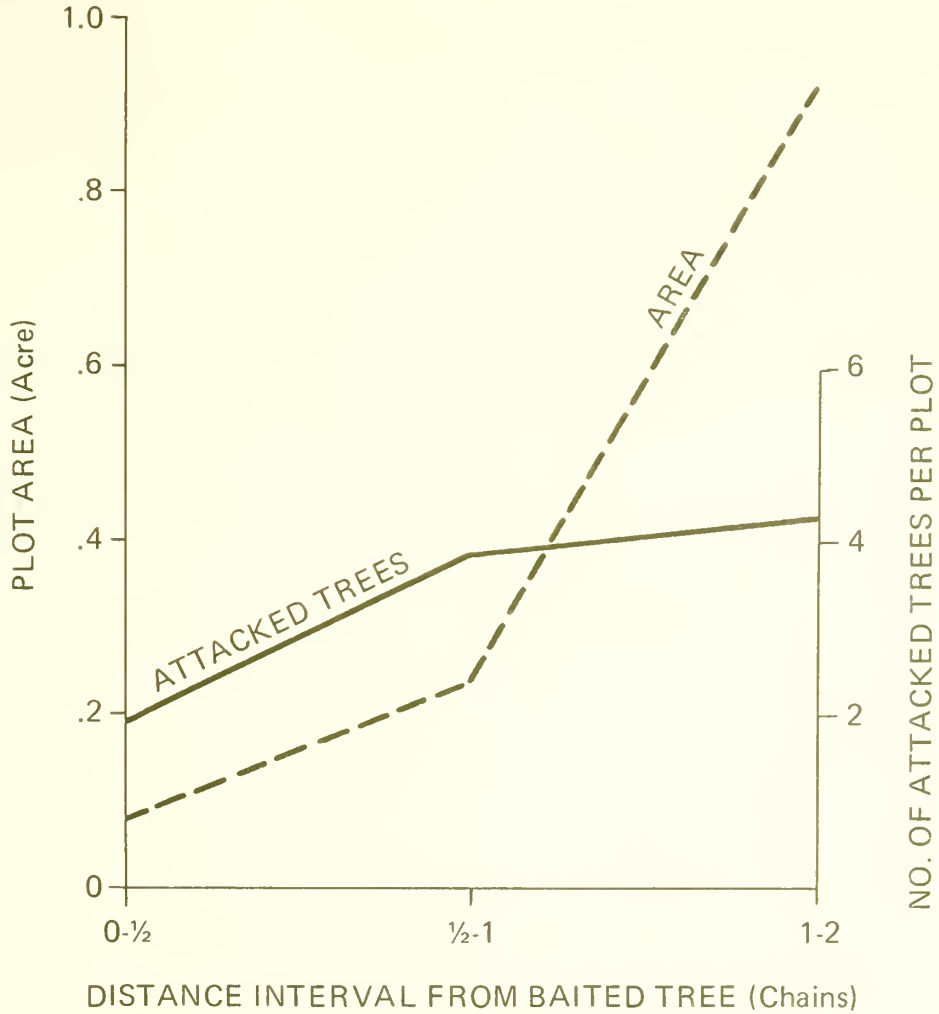

Figure 3.--Relationship of number of attacked Douglas-firs and plot area by distance from baited tree.

ACKNOWLEDGMENTS

We were aided in the field by D. Kuehn, S. McCoy, and R. Rains of Potlatch Corporation; J. M. Wells and R. D. Oakes of the Intermountain Station, Forestry Sciences Laboratory, Moscow; and T. L. Brock and T. J. Stygar of the Idaho Department of Public Lands. We were aided in defining technology for this study, interpretation of some of the results, and review of the manuscript by Dr. Gary B. Pitman, Boyce Thompson Institute.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 — 677-093 / 34 REGION NO. 8

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USDA FOREST SERVICE RESEARCH NOTE INT-190

STEM SURFACE AREA EQUATIONS FOR FOUR TREE SPECIES OF NEW MEXICO AND ARIZONA

David W. Hann and Robert K. McKinney, Jr.[1]

ABSTRACT

Presents surface area equations for ponderosa pine ("yellow" and "blackjack" pine both separately and in combination), Douglas-fir, and a combination of Mexican white pine and white fir. The basic data came from three National Forests in Arizona and New Mexico, and were analyzed using weighted least squares regression techniques. Also presented are equations for predicting surface area of forked trees.

OXFORD: 536
KEYWORDS: stem, surface area, weighted least squares regression, unforked trees, forked trees, analysis of covariance, residuals

The total stem surface area of a tree is the area of the bole surface inside bark, excluding the end areas, from the ground to the tip of the tree. It is equivalent to the area of a sheet of paper wrapped around a form which approximates a paraboloid or cone. The use of surface area, when combined with cubic-foot volume and length (tree height), to predict product recovery from trees and logs has been described by Grosenbaugh (1954), Davis and others (1962), and Bruce (1970). Lexen (1943) and Husch (1963) suggested total stem surface area per acre as a measure of growing stock for estimating stand growth. Stand surface area inside bark is equivalent to area of the lateral meristem, where volume growth occurs.

The lack of surface area equations which could be used in product recovery studies in the Southwest stimulated the research reported here. This paper describes methods used to develop surface area equations as a function of total tree height and d.b.h. for four species (one with two vigor types) or species groups.

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SOURCE AND NATURE OF DATA

The data were collected by field crews from the Division of Timber Management, Southwestern Region, USDA Forest Service, located in Albuquerque, New Mexico.

Species and Forests were:

Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco) from the Lincoln and Tonto National Forests.

Mexican white pine (*Pinus flexilis* var. *reflexa* Engelm.) from the Lincoln National Forest.

White fir (*Abies concolor* [Gord. and Glend.]) from the Lincoln National Forest.

"Blackjack pine" (*Pinus ponderosa* Laws.) from the Lincoln, Coconino, and Tonto National Forests.

"Yellow pine" (*Pinus ponderosa* Laws.) from the Lincoln, Coconino, and Tonto National Forests.

Foresters in the Southwest separate "blackjack" and "yellow" pines on the basis of growth vigor. The distinction is meaningless botanically but, because of the differences among trees and stands of low and high growth vigor, it is useful in forest management.

This study was coordinated with the continuous forest inventory (CFI) program in the Southwestern Region. A subsample of the 10-point clusters measured in the CFI program was randomly drawn for each Forest. On the Coconino and Tonto National Forests, all of the trees located on the 10-point cluster were felled and measured using procedures similar to those described by Stage and others (1968). Because of a lack of funds, and for safety reasons, not all of the trees were felled on the Lincoln National Forest. Instead, trees were selected to insure representation from all of the diameter classes in the cluster.

EXPECTED MODEL FORMS

Sample tree surface areas were calculated with a modified version of the NETVSL computer program (Stage and others 1968). Before the output from NETVSL was examined, expected model forms were developed. The expected model forms were used to recognize and predict the relationship between surface area and the independent variables of total tree height and d.b.h.

Three simple geometric forms were considered. A tree stem, or portions thereof, can be approximated by a cylinder, cone, or paraboloid. The surface area for each geometric solid can be expressed by the following formulas (Husch 1963):

FORM	*FORMULA*
Cylinder	$SA = 2\pi rh$
Cone	$SA = \pi r(r^2 + h^2)^{1/2}$
Paraboloid	$SA = [(\pi r)/(6h^2)][(4h^2 + r^2)^{3/2} - r^3]$

where SA = surface area

r = radius of the base, in feet
h = height of the form, in feet

Although the surface area formulas for the cone and the paraboloid appear complex, simplified formulas can be derived without great loss of accuracy. For tree stems, the radius (when expressed in feet) is small compared to height. Therefore, when the height and radius are squared (or cubed) and added (or subtracted) together, the radius contributes little to the result. Hence, the two formulas were simplified:

FORMULA FOR CONE	*FORMULA FOR PARABOLOID*
$SA = \pi r(r^2 + h^2)^{1/2}$	$SA = [(\pi r)/6h^2)][(4h^2 + r^2)^{3/2} - r^3]$
$SA \simeq \pi r(h^2)^{1/2}$	$SA \simeq [(\pi r)/6h^2)][(4h^2)^{3/2}]$
$SA \simeq \pi rh$	$SA \simeq 4/3\pi rh$

From this simplification, it was apparent that the major difference among the surface area formulas was the constant of 2π for cylinders, $4/3\pi$ for paraboloids, and π for cones. The expected model, therefore, is the linear relationship:

$$\text{Surface Area} = b_o + b_1(DH)$$

where D = diameter at breast height, in inches

H = total tree height, in feet

b_o = an intercept which should range from 0 to 4.0 square feet. An intercept can be expected because trees 4.5 feet tall or less have DH = 0.

b_1 = a constant, which should range from $\frac{4\pi}{(3)\ (24)}$ to $\frac{\pi}{24}$ (or from 0.1745 to 0.1309) because trees are between a cone and a paraboloid in shape.

ANALYSIS OF UNFORKED TREE DATA

Surface area of unforked trees was plotted over d.b.h. and tree height to determine what samples might be combined. The following tabulation indicates the initial species and National Forest combinations used to develop surface area equations, and the number of observations in each combination. The plotted data also indicated that variance about a regression line would be related to the independent variable, DH.

Species and National Forest	*Observations*
Douglas-fir on the Lincoln and Tonto National Forests	107
Mexican white pine and white fir on the Lincoln National Forest	77
Blackjack pine on the Coconino National Forest	285
Blackjack pine on the Lincoln and Tonto National Forests	395
Yellow pine on all Forests	165

Least squares regressions of surface area on DH were fitted for the initial species groupings. Observation weights proportional to $1/(DH)^2$ were used to obtain minimum variance estimators of regression coefficients. This initial estimate was based on work with tree volume equations (Cunia 1964), which found that the square residuals increased linearly with the square of the independent variable.

Analysis of covariance (Freese 1964) was used to test for differences between the surface area equations for blackjack pine on the Coconino National Forest and for blackjack pine on the Lincoln and Tonto National Forests. This analysis (table 1) indicated that the differences were not significant at the 5 percent confidence level, so the data from the three Forests were combined and a general equation for blackjack pine was developed. This equation was next tested against the yellow pine equation and the

Table 1.--*Analysis of covariance: comparison of coefficients for unforked blackjack pine equation on the Coconino National Forest and unforked blackjack pine equation on the Lincoln and Tonto National Forests*

ecies location l items tested	Degrees of freedom	Residual Sum of squares	Residual mean squares	Calculate F
conino	283	2,126.34	7.5136	--
ncoln and Tonto	393	3,517.91	8.9514	--
Total	676	5,644.25	8.3495	--
fference for testing slopes	1	2.94	2.94	0.3521 N.
oled values	677	5,647.19	8.3415	--
fference for testing levels	1	1.51	1.51	.1813 N.
ngle equation	678	5,648.70	8.3314	--

Table 2.--*Analysis of covariance: comparison of coefficients for unforked yellow pine equation and unforked blackjack pine equation*

species and m tested	Degrees of freedom	Residual Sum of squares	Residual mean squares	Calculate F
llow pine	163	25,564.70	156.8390	
ckjack pine	678	5,591.36	8.2468	
Total	841	31,156.06	37.0464	
fference for testing slopes	1	695.44	695.44	18.772**
led values	842	31,851.50	37.8283	

difference between the equations was significant at the 1 percent confidence level (table 2). However, an equation combining yellow and blackjack pine was also developed for users of these equations who do not differentiate between yellow and blackjack pine. This must be regarded as an equation with an omitted variable--growth vigor. As Kmenta (1971) demonstrated, this could result in biased estimates of the regression coefficients. This situation should not be unduly alarming. The bias involved is a bias of the estimated coefficient as an estimator of the true parameter relating surface area to DH. So long as the equation is used to predict surface area for trees which have the same relationship between DH and the omitted variable, predictions will be unbiased, though inefficient.

Using the final species-Forest groups, the following model was fitted by least squares regression to further examine the form of the residuals:

$$\ln [(\text{Actual SA-Predicted SA})^2] = c_o + c_1 \ln (DH)$$

The coefficient c_1 in this equation estimates the power by which the squared residual increases with an increase in DH. The calculated c_1 values are presented in table 3. The powers of DH are close to 2 (the power which was assumed earlier) for all species except yellow pine, which is closer to 1.

Table 3.--*Coefficients for equations of residuals and certain related regression statistics*

Species group	C_0	C_1	Standard error of C_1	Mean square residual (MSR)
Ponderosa pine	-10.78196	2.04002	0.092805	5.00786
Yellow pine	-4.56996	1.19232	.375083	5.13841
Blackjack pine	-9.75613	1.85458	.125818	5.04500
Douglas-fir	-9.77705	1.83869	.220917	3.57956
Mexican white pine, white fir	-9.98315	1.88056	.304233	6.45851

An estimate of the mean squared residual about the regression surface, as conditioned by DH, can be obtained from the equation:

$$\hat{S}^2_{y \cdot x} = e^{[c_o + c_1 (DH) + \frac{MSR}{2}]}$$

where $\frac{MSR}{2}$ = 1/2 mean square residual, which is necessary for conversion of logarithmic estimates to arithmetic units (Baskerville 1972).

A final set of surface area regressions was then fitted with observation weights proportional to $1/(DH)^{c_1}$. These equations and certain regression statistics are presented in table 4. The equation for ponderosa pine was forced through the origin because the intercept was negative, which violated the expected model form. All other coefficients meet expectations.

For those who wish to calculate estimated confidence intervals for predicted values of surface area, the values for mean weighted DH and the weighted corrected sum of squares have been included in table 4.

Table 4.--*Surface area equations and certain regression statistics*

Species group	Surface area equation	Sy·x (Weighted root mean square residual)	Weighted mean DH	Corrected weighted sum of squa
onderosa pine	0.146150(DH)	3.2655	242.064	82,142,10
ellow pine	3.10548 + .149661(DH)	4.8301	1,351.650	83,183,30
lackjack pine	0.52975 + .143295(DH)	3.0411	248.056	21,302,20
ouglas-fir	3.31473 + .130655(DH)	3.8076	360.927	10,561,30
exican white pine, white fir	2.01727 + .137988(DH)	4.6509	298.479	9,370,90

ANALYSIS OF FORKED TREE DATA

Forked tree data were grouped by species, surface areas were plotted over d.b.h. and height, and resulting trends examined. The initial grouping of data and the number of observations for each group were:

Species	*Observations*
Blackjack pine	62
Yellow pine	15
Douglas-fir, Mexican white pine, white fir	19

The data were next examined by calculating the ratio of the actual forked tree surface area divided by the predicted surface area for a normally formed tree and plotting this ratio over d.b.h., over height of the tallest stem, and over the ratio of height to fork divided by height of the tallest stem. No relationship was apparent over d.b.h. or over height of the tallest stem, but there was a relationship over the ratio of height to fork divided by height of the tallest stem. This relationship appeared to take the form:

$$\left(\frac{FSA}{PSA}\right) = d_o - d_1 \left(\frac{FH}{TH}\right)$$

where FSA = forked tree surface area, in square feet
PSA = predicted tree surface area, in square feet, for an unforked tree of the same d.b.h. and height
FH = height to fork, in feet
TH = height of tallest stems in the forked tree, in feet

Physical considerations require that as the position of the fork approaches the tip of the tree, the predicted forked tree surface area should approach the prediction for an unforked tree. To meet this requirement, the following model was fitted through the origin for each species group:

$$\left(\frac{FSA}{PSA}\right) - 1 = f\left[1 - \left(\frac{FH}{TH}\right)\right]$$

This model can then be changed back to the original form through these transformations:

$$d_o = 1 + f$$

$$d_1 = (-f)$$

Analysis of covariance was then used to test differences in coefficients for the three species groups. No significant differences were found at the 5 percent confidence level (table 5), so the data were combined and the following regression was fitted:

$$\left(\frac{FSA}{PSA}\right) = 1.214839 - 0.214839\left(\frac{FH}{TH}\right)$$

To use this equation, the predicted surface area for a normally formed tree is calculated using the equations previously presented in table 4. This predicted surface area is then multiplied by the value calculated in the above equation to estimate the forked tree's surface area. For those users who do not measure the height to the fork, the following equation can be used:

$$\hat{FSA} = 1.086481\ (PSA)$$

where $\hat{FSA}$ = estimated forked tree surface area in square feet. This equation is based on the mean value of $\left(\frac{FSA}{PSA}\right)$.

Table 5.--*Analysis of covariance: comparison of coefficients for forked tree equations*

Species and items tested	Degree of freedom	Residual sum of squares	Residual mean squares	Calculated F
Blackjack pine	60	0.572876	0.0093914	
Yellow pine	13	.301581	.0215415	
Douglas-fir, Mexican white pine, white fir	17	.193569	.0107539	
Total	90	1.068026	0.0118670	
Difference for testing slopes	2	.032780	.0163900	1.3811 N.S.
Pooled values	92	1.100806	.0119653	

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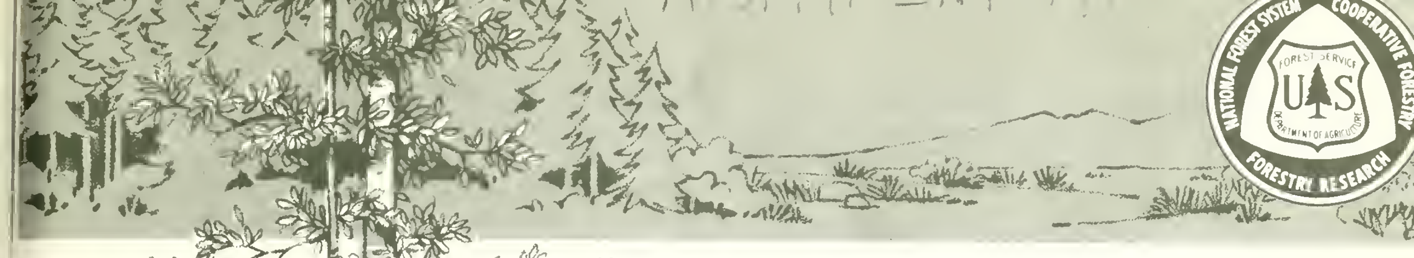

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USDA FOREST SERVICE RESEARCH NOTE INT-191

SITE INDEX AND MAXIMUM GROSS YIELD CAPABILITY EQUATIONS FOR PONDEROSA PINE IN THE BLACK HILLS

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ABSTRACT

A mathematical model capable of use with computers or sophisticated calculators is derived from site index curves commonly used in management of ponderosa pine in the Black Hills. A second equation permits conversion of site index estimates to a maximum gross yield capability rating expressed in cubic feet of wood per acre per year.

OXFORD: 541; 547
KEYWORDS: Site index, yield capability, maximum gross yield capability, ponderosa pine, Black Hills.

Site index (height of the dominant stand at a base age) has been used for many years to estimate site quality (Husch 1963). Much of the site index information still in use was developed years ago and presented in the form of tables and graphs which are not readily usable in computer programs (Brickell 1970). Hornibrook's (1939b) site index curves for ponderosa pine (*Pinus ponderosa* Laws.) in the Black Hills are still accepted as adequate for use in stands which have site trees 70 years old, or older, with class B crowns. It is desirable, therefore, to have a mathematical model of Hornibrook's site curves which can be used with today's electronic computers and calculators capable of being programed.

It is also worthwhile to have the means of converting a site index estimate to a productivity rating expressed in cubic feet of wood per acre. Forest Survey has for some time used yield capability to rate the wood-producing potential of forest land. The yield capability measure used for this purpose is defined as "...mean annual increment of growing stock attainable in fully stocked natural stands at the age of culmination of mean annual increment."

A problem with the use of this definition in the Black Hills and similar areas is that very few "natural stands" exist. Most stands have received repeated silvicultural treatments, and the density of such stands is far below the density of stands upon which most existing normal yield tables were based. Neither density may result in the site achieving maximum productivity. Also, in natural stands a portion of the site's production is lost to mortality, and this loss is not considered in Forest Survey's conventional definition of yield capability. This can lead to unrealistic estimates of potential productivity. Yield capability estimates based on normal yield tables are also influenced by utilization standards implicit in the tables. Such standards vary from one set of yield tables to another, and in any case may not reflect the site's full fiber production potential.

To avoid these problems the site's potential to yield wood should be expressed as the maximum amount of wood fiber producible on the natural site, regardless of stand size and stocking. A "natural" site is one that has not been modified through fertilization, irrigation, or the planting of genetically superior trees.

"Maximum gross yield capability" would be based on the culmination of mean annual gross increment in total stemwood cubic volume per acre. Total cubic mean annual gross increment is defined as the sum of the total stem cubic volume of all trees in the residual stand, at a specified age, plus the accumulated total stem cubic volume of all trees removed by thinning, mortality, or both, divided by stand age. Separate relationships could then be developed that would tie the site's maximum gross yield capability and stand density to the yield of the desired end product. Myers' (1971) computer program, PONYLD, which produces yield tables for managed ponderosa pine stands in the Black Hills, has made it possible to develop a maximum gross yield capability equation for that area.

The site index and maximum gross yield capability equations presented here were developed using Matchacurve techniques (Jensen 1964; Jensen and Homeyer 1970, 1971). These procedures were used because in both cases the task was to find an equation to describe a set of essentially smooth curves. Both models have been tested on a Monroe 1666[1] calculator so they should be usable with other calculators having similar capabilities.

Stocking levels that resulted in maximum gross yield capability are not recommended as the best stocking levels for management. Many other factors must be considered in management decisions.

SITE INDEX EQUATION

Hornibrook's site index curves are anamorphic, with a base age of 100 years, and are presented for site indices 40, 50, 60, 70, and 80. Average total age and average total height, in feet, for vigor class B trees, 70 years old or older, were needed data for determining site index. Hornibrook (1939a) modified Keen's tree classification for the Black Hills to define vigor class B trees as ones with "fair to moderately vigorous crowns with average width or narrower, and length less than 55 percent of the total height; either short wide crowns or long narrow ones, but not sparse or ragged; may be flat on one side, position either dominant or codominant but sometimes isolated."

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[1]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U. S. Department of Agriculture of any commercial product or service.

The site index equation developed from Hornibrook's curves is:

$$S = \frac{H}{X} - 0.3846$$

where

$X = -0.5234 + 1.8234 \cdot \exp\left[-[1.0989 - 0.006105(A)]^{2.35}\right]$

S = Site index, base age 100 years

H = Average total height of four to six vigor class B trees, in feet

A = Average total age of four to six vigor class B trees in years (if age is greater than 180 years, use 180 years in the equation)

A visual check of this model was made by plotting the predicted site index curves and comparing them to Hornibrook's site index curves. The curves were very close to each other, never differing more than one site index unit. Hornibrook's curves were drawn for ages from 70 to 360 years and for heights between 25 and 100 feet. Therefore, extending the use of this equation is not recommended. There is no assurance that the trends presented by Hornibrook can be extended beyond his curves.

MAXIMUM GROSS YIELD CAPABILITY EQUATION

Myers' PONYLD yield program allows the user to specify: (1) Initial values of stand age, mean stand diameter, and number of trees per acre; (2) maximum growing stock level to be maintained after initial or intermediate thinnings, once a mean stand diameter of 10 inches has been reached; (3) the length of time between thinnings; (4) the stand's site index; and (5) other items not of primary importance in this analysis. This flexibility allows a very large number of combinations of these variables to be tested to determine which combination would produce maximum gross yield capability. To reduce the number of combinations to a reasonable level, some assumptions were made.

First, only site index values from 30 to 100, in increments of 10, were examined. This assured coverage corresponding to the range of Hornibrook's site curves.

Second, the initial values of stand age, mean stand diameter, and number of trees per acre for each site index level were either equated to or extrapolated from the quantities given by Myers (1966). These values are probably representative of stand conditions in Black Hills ponderosa pine.

Finally, the thinning cycle was tested only for values of 10, 20, and 30 years. These seemed to cover a reasonable range of cutting cycles for the Black Hills.

With these assumptions, maximum growing stock level was then screened for each cutting cycle to determine which combination produced maximum gross yield capability at each site index level. PONYLD was modified by the author to include total cubic mean annual increment within the program.

In the first screening, the initial thinning level was set equal to the stocking level for the intermediate thinnings. This was done to reduce the range of values examined in the next step. The second screening allowed the initial thinning level to change as well as the intermediate thinning level. The results of these screening runs indicated that total cubic mean annual increment was maximized when the initial and intermediate stocking levels were equivalent. They also showed that the calculated mean annual increments departed somewhat from the expected values.

To help smooth out the irregularities, the maximum gross yield capability was picked for each stocking level-cutting cycle-site index combination. The age and stocking level at which these maximum gross yield capabilities occurred were plotted over site index for each cutting cycle, and linear equations were developed.

These equations were then used to calculate a "smoothed" age and stocking level for each site index and cutting cycle combination. The appropriate maximum gross yield capabilities for these "smoothed" values were then picked from the tables and used as final values for the rest of the analysis.

Examination of the maximum gross yield capabilities for each cutting cycle indicated that the 20-year cycle produced slightly higher values, so it was used in the development of the equation:

$$MGYC = -32.47 + 203.97 \cdot \exp\left[-[1.8117 - 0.01647(S)]^{1.024}\right]$$

where

MGYC = Maximum gross yield capability in cubic feet per acre per year

S = Site index, base age 100 years

The use of this equation should be restricted to site indices ranging from 30 to 100. In tabular form, maximum gross yield capability for these site indices is:

Site index	*Maximum gross yield capability* *ft^3/acre/yr*
30	21.67
40	31.67
50	43.48
60	57.39
70	73.77
80	93.01
90	115.53
100	141.74

For the 20-year cutting cycle, the relationship of site index to age and stocking level of MGYC was found to be:

$$A = 210 - S$$

$$St = 80 + S$$

where

A = Age, in years, at which gross yield capability maximized

S = Site index, base age 100 years

St = Stocking level, in square feet of basal area per acre (after mean stand diameter reaches 10 inches) at which gross yield capability maximized

It should be remembered that these stocking levels are not being recommended as the best stocking levels for management. Rather, they are the stocking levels at which maximum gross yield capability was indicated.

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USDA Forest Service
Research Note INT-192

April 1975

SINGLE DIMENSION, MULTIPLE DEVELOPMENT THIN-LAYER CHROMATOGRAPHY OF SUGARS FOR DENSITOMETRIC QUANTIFICATION

Neil E. Martin and B. L. Welch[1]

ABSTRACT

Efficacy of certain combinations of thin-layer chromatography media and solvents in qualifying and quantifying sugar mixtures is illustrated. Mixtures were partitioned into subgroups and then resolved into their constituents by selective use of media, solvents, and the technique of multiple development. Acceptance was further based upon applicability for in situ densitometric quantification, such as providing discrete separations, minimum background interferences, and circular to elliptical spot configurations.

OXFORD: U545.844; 892.68
KEYWORDS: Chromatography (thin layer), sugars, densitometry

The utility of thin-layer chromatography (TLC) in qualitative and quantitative analyses of the components of sugar mixtures is documented in numerous publications (DeStefanis and Ponte 1968; Hay and others 1963; Jeffrey and others 1969; Ovodov and others 1967; Vomhof and Tucker 1965; Wolfrom and others 1965 and 1966). Thin-layer chromatography has inherent features that make it a desirable tool for quantification of carbohydrates in plant tissues. These features include numerous combinations of chromatographic adsorbents and solvents, convenience of separations of mixture constituents in short development times, and capability of using small quantities of samples.

With TLC techniques, sugars, ranging from simple molecules to polymers, are identified and quantified in many kinds of plant materials. However, selection of appropriate TLC adsorbents and solvents evolves from research needs or sets of special circumstances associated with the sugar constituents being studied and so are derived empirically. Our research needs would be satisfied through use of a densitometer to quantify some common sugars extracted from western white pine tissues. The techniques reported here were those we selected using commercially available compounds and are those we found most applicable to identification and densitometer instrumentation.

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[1]Research scientist stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho, and biological laboratory technician stationed in Logan, Utah, at the Forestry Sciences Laboratory, maintained in cooperation with Utah State University.

Lack of prior knowledge of the qualitative nature of the sugar mixture in an extract of plant material can result in considerable trial and error in selecting the appropriate TLC system. Time spent in this activity can be minimized by employing the principles used by Gordon and others (1962). TLC adsorbents and solvents are used that first partition sugar mixtures into such general groups as pentoses, hexoses, and disaccharides. Then, the constituents of interest within a group can be resolved from each other with select solvents and multiple developments (Thoma 1963) since the sequence of R_f values for carbohydrates is the same in most solvents, except phenol-water (Isherwood and Jermyn 1951).

Quantitation via in situ densitometry of sugars on TLC media imposes more stringent qualifications for acceptable chromatographic separations than qualitative studies of the same sugar mixtures. The TLC system must provide spot geometries compatible with the densitometer, achieve high resolutions of sample constituents, and must result in minimal background interferences (Chandler and Barton 1955; Goldman and Goodall 1968; Novacek 1972). Each or all of these problem elements can contribute error to the extent that mixtures of soluble sugars of special interest in plant physiology research cannot be quantitatively analyzed.

EXPERIMENTAL

Developing solvents

The following solvents were used for the separation of monosaccharides, disaccharides, trisaccharides, and tetrasaccharides. Proportions in parts by volume follow:

A. 1-butanol:acetic acid:water,8:2:3
B. Chloroform:acetic acid:water,50:35:5
C. Isoamyl alcohol:pyridine:water,4:4:1
D. Ethyl acetate:pyridine:water,8:2:1
E. Ethyl alcohol:pyridine:water,8:2:1

Localizing reagent

2 g diphenylamine, 2 ml aniline, 200 ml acetone, and 20 ml phosphoric acid (85%).

TLC media

Eastman	#6060, silica gel, 100μ, polyvinyl binder, acetate sheets.
	#6064, cellulose, 160μ, no binder, acetate sheets.
Brinkman	#5765, silica gel, 250μ, unspecified organic binder, glass plate.
	#5754, cellulose, 80μ, no binder, glass plate.
Gelman	ITLC-SA, impregnated glass fiber.
	ITLC-SG, impregnated glass fiber.

Activation of TLC sheets

Each 5- by 20-cm acetate sheet coated with silica gel adsorbent was dipped into a 0.1 M monobasic potassium phosphate solution and then dried for 90 minutes at 85°C (Lato and others 1968; 1969). The dried sheets were stored over calcium chloride desiccant at room temperature until needed.

Chromatographic procedures.

The sugars were dissolved in distilled water and applied to the chromatographic adsorbents with a microsyringe in 0.1 μl quantities (with intermittent cool drying) until 2 μg of each sugar was accumulated. When 1 μg quantities of each sugar were used, color intensities for all except glucose were barely visible, whereas increases in quantities beyond 3.5 to 4.0 μg exceeded the capacity of the TLC media and resulted in such excessive tailing of spots that separations between some sugars were obliterated. The plates were developed in preequilibrated battery jars or ITLC chambers.

Detection of carbohydrate compounds

The developed plates were air dried and dipped into the localizing reagent. Silica gel plates were air dried for 15 minutes and then placed in a 100°C oven for 10 minutes. Cellulose plates were heated for 4-5 minutes at 110°C.

Densitometric procedure

Sheets and plates were cut into strips to fit the densitometer carrier. Scans were performed at 1:1 and 1:3 scan to recorder speeds by using a 300-400 nm light filter and a slit 10 mm by 0.5 mm or 10 mm by 1.0 mm in width or a variable width slit insert.

RESULTS AND DISCUSSION

In our laboratory, we have selected TLC media, developing solvents, and localizing techniques that provide cursory identification of sugar groups within mixtures fabricated from commercial sources. Then, certain developing solvents were used to resolve these groups into their constituents. Criteria for in situ densitometric quantitations such as discrete separations, minimum background interferences, and circular to elliptical spot configurations were met by the systems reported.

TLC Media

ITLC-SA and ITLC-SG sheets were unsatisfactory with any of the solvents tested. These media handled well and accepted the test samples without evident problems, but were unacceptable for quantification of individual sugars because of excessive tailing and absence of resolution between sugars within a group.

Brinkman glass plates also proved to be troublesome for our specific applications since scoring them into inch-wide strips to fit the densitometer carriage resulted in many unusable chromatograms. Samples were easily applied to either cellulose or silica gel adsorbents. However, overdrying as aliquots were applied to both adsorbents resulted in samples staying tenaciously at the origin. This spot, localized at the origin, is easily recognized by its circular configuration and highly delimited border and should not lead to false interpretations.

Silica gel media provided backgrounds that were superior to cellulose adsorbents for measurements of sugar concentrations with in situ densitometric instrumentation (fig. 1). The reaction of the localizing reagent with the cellulose media produces a background that varies from light to dark blue within and between chromatograms. Errors in quantitation resulting from background interferences were large enough to mask differences between sugar concentrations. In contrast, the white background of silica gel adsorbents provided a consistently low integrator baseline and easy visualization of the blue, yellow, and green colors of localized sugars (fig. 1-A).

Development Techniques

Although both cellulose and silica gel adsorbents, in combination with specific solvents, provided in three developments reproducible separations between certain sugars acceptable for quantitation of individual sugars, our impression was that silica gel impregnated with phosphate provided the best resolution. All adsorbent solvent combinations were useful in qualitative applications preliminary to quantitative analysis. In all instances, one development was of marginal value, two developments provided greater insight into the constituents of a sugar mixture, and three developments provided the resolution required for quantification (fig. 1-B). However,

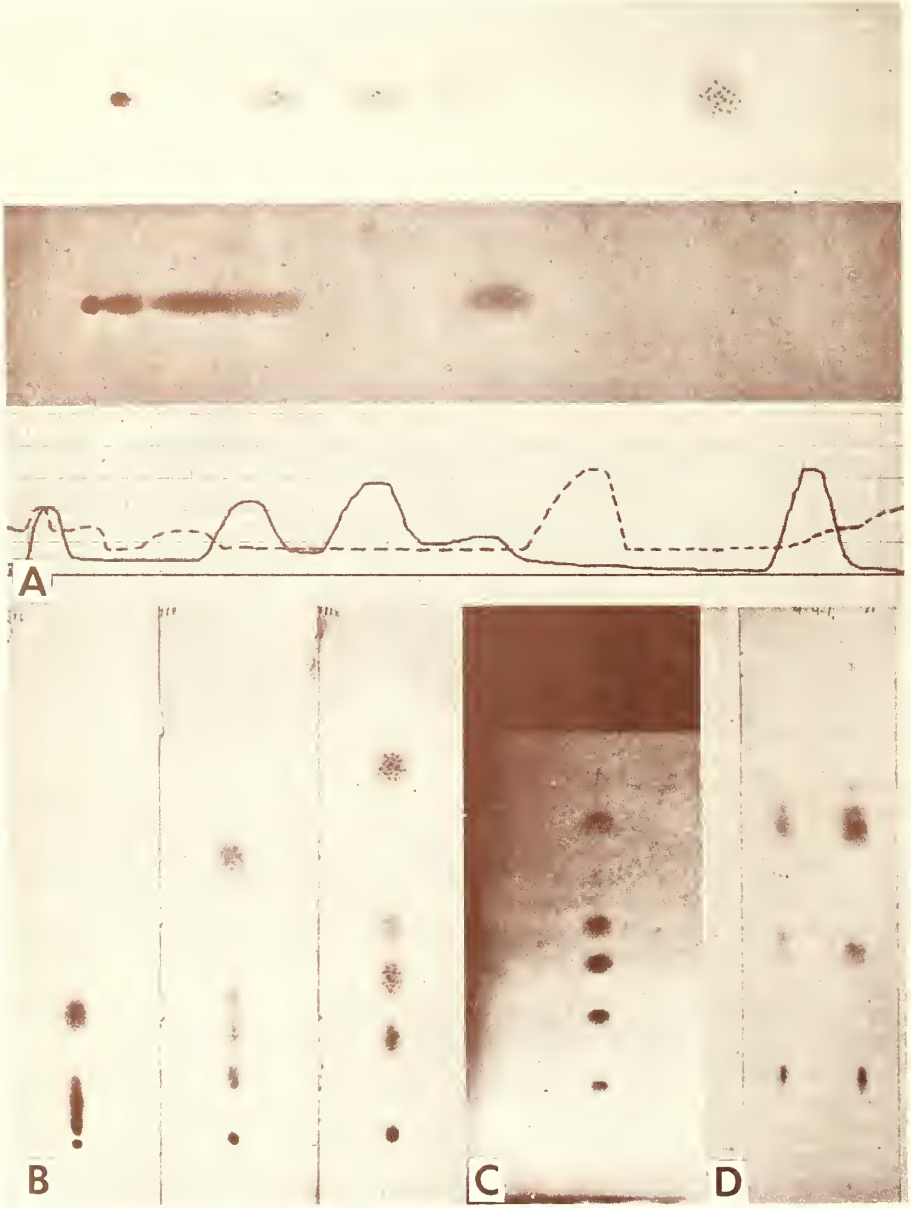

Figure 1.—A. Densitometer traces illustrating differences in light absorbency between silica gel (upper TLC strip, solid trace) and cellulose media (lower TLC strip, dash trace). Scan to trace ratio 1:3. B. Three step multidevelopment of a mixture of rhamnose, fructose, glucose, sucrose, and raffinose. Solvent D and silica gel. C. Preliminary qualification of a mixture of sugars with solvent A, cellulose, and three developments. Black mask used to illustrate solvent front. D. Movement of trisaccharides and tetrasaccharides from the origin into the lower half of the silica gel chromatogram and resolution between raffinose and stachyose obtained with three developments in solvent C.

solvent A (1-butanol:acetic acid:water) in combination with either silica gel or cellulose was the only exception to production of circular or slightly elliptical spots. This feature distracts from its usefulness in quantitative, but not in qualitative, analyses of sugar mixtures.

Solvents

Mixtures of sugars were first partitioned into groups and then select groups partitioned into the constituents by means of certain combinations of solvent, media, and multiple ascending developments (table 1). Solvents containing ethyl acetate had an appreciably shorter time for each development than solvents containing 1-butanol or chloroform. Of all solvent and adsorbent combinations tried, solvent A in combination with cellulose gave the best spread of a mixture of sugar groups (fig. 1-C). In conjunction with movement of all compounds from the origin, the separation of sugar groups utilized nearly the entire length of the solvent migration. Pentoses occupied an area of the chromatograms nearest the solvent front. Hexoses and disaccharides were found midway on the chromatograms, and high molecular weight trisaccharides and tetrasaccharides near the origin. The combinations of solvent C and cellulose or silica gel, or solvent D and silica gel were almost equivalent to the above system in separating capacity. However, fructose, glucose, and sucrose are very close together; consequently, the possibility of other sugars being in this area would be overlooked. The benefits of solvent C and silica gel are the separation of raffinose and stachyose and their movement away from the origin allowing quantification and permitting identification of the number of sugars in this area (fig. 1-D).

Table 1.--*Media and solvent combinations used to resolve certain sugar mixtures. Position in table relative to other groups is similar to area occupied on chromatogram*

Cellulose TLC media		Silica gel TLC media	
Sugars	Solvents	Sugars	Solvents
Rhamnose Ribose Xylose Fructose	Ethyl acetate:pyridine:water(8:2:1)	Rhamnose Ribose Xylose Fructose	Ethyl acetate:pyridine:water(8:2:1)
Arabinose-fructose Sorbose Mannose Glucose	Chloroform:acetic acid:water(50:35:5)		
Sorbose-fructose Glucose Galactose Sucrose	Ethyl acetate:pyridine:water(8:2:1)		
		Glucose Galactose Lactose-melibiose Raffinose	Chloroform:acetic acid:water(50:35:5)
Melezitose Raffinose Cellobiose	Chloroform:acetic acid:water(50:35:5)	Cellobiose Melezitose Raffinose	1-butanol:acetic acid:water(8:2:3)

Two solvents, A and B, were satisfactory in carrying disaccharides, trisaccharides and tetrasaccharides from the origin to the center area of chromatograms, provided the proper TLC media were used. For example, mixtures of four disaccharides were separated into sucrose, maltose, and lactose-melibiose spots with solvent B and silica gel media, but no separations occurred when cellulose media were used. The disaccharide and trisaccharide mixture, cellobiose, melezitose, and raffinose, separated into three spots in the solvent A-silica gel combination, but extended into a long, indecipherable spot when solvent B was used.

Partitioning of simple sugars within the pentose and a methylated derivative, rhamnose, of the hexose group was accomplished with ethyl acetate, pyridine, and water (solvent D) on cellulose media. Within this group of sugars, rhamnose, ribose, xylose, and fructose were satisfactorily separated from each other, with the entire group occupying more than the upper half of the chromatogram. Fructose, glucose, sucrose, and raffinose separated well, but with not enough distance between sugars to allow identification of other hexoses and disaccharides. When using the same solvent on silica gel, a greater separation between rhamnose and ribose and between xylose and fructose occurred, but ribose and xylose were contiguous.

Chloroform, acetic acid, and water (solvent B) in combination with cellulose provided satisfactory separations between sugars of a mixture of hexoses and disaccharides. Glucose, mannose, and sorbose were separated from each other and from a spot containing arabinose and fructose. Separations between constituents having positions lower than glucose on the chromatograms were found to be satisfactory in the solvent D-cellulose media combination. This method was used to separate glucose, sucrose, galactose, and raffinose from each other, at the expense of sorbose and fructose, which occupied a spot above glucose.

SUMMARY

Because of the diversity of sugar compounds, it is unlikely that a single solvent system will completely resolve a mixture of them into discrete spots on a chromatogram acceptable for densitometric quantitation. However, solvents and TLC media combinations can be used to fractionate a mixture into groups within which the sugars have some common characteristics. Solvents and TLC media effective in influencing the migration of the group constituents can then be used to resolve them and also to provide symmetrical circular or elliptical spots.

We found solvent A (1-butanol:acetic acid:water) in combination with cellulose to be a satisfactory system for the partitioning of a mixture of a pentose, hexose, disaccharide, trisaccharide, and tetrasaccharide over the distance traveled by the solvent. All solvent and media combinations provided the same sequential order of these groups, but differed in influencing the spread between and within groups. In applying our findings to quantitative analysis of pine tissues, the ethyl acetate, pyridine, and water solvent with silica gel was preferred to separate three sugars within the pentose and methylated hexose derivative group. Chloroform, acetic acid, and water solvent performed best in separating for quantification the constituent pine hexoses and disaccharides or disaccharide, trisaccharide, and tetrasaccharide mixtures.

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USDA Forest Service
Research Note INT-193

April 1975

TRAIL DETERIORATION IN THE SELWAY-BITTERROOT WILDERNESS

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ABSTRACT

The relationship of environmental factors to trail deterioration in the Selway-Bitterroot Wilderness of Idaho and Montana was studied from June through November of 1972. Trail erosion was quantified by using a cross-sectional area loss index. Landform, vegetative habitat type, and trail grade have a greater effect on erosion and bog formation than elevation, aspect, parent material, sideslope, soil horizon depths, or amount of use. Landslides or mass failure of trails were most related to side slope, landform, and vegetative habitat type. Biophysical units that combine important landform and vegetative habitat types are proposed as the basis for planning trail construction and maintenance. Trail location, construction, and maintenance standards are described for several sample biophysical units. Tentative management guidelines are suggested.

OXFORD: 686.3; 116.6
KEYWORDS: trails; erosion control

Covering more than 1-1/4 million acres in Idaho and Montana (fig. 1), the Selway-Bitterroot Wilderness is one of the largest areas of wilderness in the Nation. There are nearly 2,000 miles of trail in the Wilderness, largely inherited from a different era. Most trails were built in the 1920's and 1930's, primarily for forest fire control, before the Selway-Bitterroot Primitive area was established in 1936. Utility and convenience, not recreational use or protection of natural conditions, were the principal design criteria. Horses were the main method of travel and dominated trail

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Figure 1.--Selway-Bitterroot Wilderness; shading delineates study area.

layout. Many sections of trail have deteriorated badly (fig. 2), a change in the natural environment that conflicts with the purpose and philosophy of the Wilderness Act. (In this report "trail deterioration" refers to changes in the trail tread, such as deep erosion, not to windfalls or brush encroachment.) Deteriorated trails are costly to maintain and detract from the visitor's wilderness experience.

The objective of this study was to determine the factors (environmental and use) that had an important influence on trail deterioration, particularly erosion, and try to relate this knowledge to trail management.

STUDY AREA

The study area covered most of the northern part of the Selway-Bitterroot Wilderness within Idaho, primarily the lower Selway River and Moose Creek drainages. There are nearly 1,000 miles of trail in the study area. This area is geologically more recent than the Rocky Mountain Sedimentaries and consists primarily of highly erosive igneous Idaho Batholith (Ross and Forrester 1958; Thomson and Ballard 1924). Higher peaks of the northeastern portion of the Wilderness have been relatively recently covered by a stagnant ice cap. Loess covers some of these peaks and ridges. The deep Selway Canyon was formed by an actively eroding river. The Moose Creek valley was extensively modified by a valley glacier.

Environments are highly varied. Elevations range from about 2,000 to over 10,000 feet, and precipitation and growing seasons have wide ranges. As a result, vegetative communities also are varied, ranging from the relatively dry ponderosa pine (*Pinus ponderosa*) communities to moist western redcedar (*Thuja plicata*) communities to cool subalpine fir (*Abies lasiocarpa*) communities. These communities are in all successional stages as a result of past wildfires.

Figure 2.--Deteriorating trails are a serious problem in the Selway-Bitterroot Wilderness and on other wildlands.

FACTORS AFFECTING EROSION

Vegetation, soil, climate, and topography are known to affect erosion (Baver and others 1972; Farmer and Haveren 1971; Yamamoto and Anderson 1967). The relationship of these environmental factors to trail erosion, a major cause of trail deterioration, can be evaluated by methods such as laboratory measurements of moisture-holding capacity, bulk density, particle size, infiltration rates, permeability, detachability, and transportability of soil material, etc. However, such methods require sophisticated measurements and facilities unavailable or impracticable for wilderness field personnel. Wilderness managers needed a reliable yet relatively simple field method to determine potentially erosive trail sites. Results of this study point toward such a field method.

1. Vegetation

Vegetation affects erosion in numerous ways. First, it provides a protective cover from raindrop splash (Farmer and Haveren 1971). Organic matter in the soil is associated with erosion (Meeuwig 1971; Baver and others 1972). Soil structure is protected by a well-rooted turf in alpine areas (Root and Knapik 1972). Root channels increase porosity, and therefore permeability of the soil. The result is less surface runoff and less erosion. Root systems also help provide the microirregularities on the surface that decrease water velocity and therefore erosion. Revegetation at varying rates in different vegetative types affects the extent of trail deterioration (Dale 1973).

2. Soil Properties

The primary soil properties affecting erosion are texture, structure, and the slope on which the soil has developed. The ability of a soil to disperse, or to be brought into suspension and to aggregate, is as important an indicator of erosive potential as is particle size or texture (Baver and others 1972). Structural type, grade, and cobble content are also important (Long 1972; Dale 1973).

3. Climate

The amount and timing of precipitation will affect the erosive potential of the site. In addition to biological relationships, climate also affects the season during which a trail is used.

4. Landforms

Baver and others (1972) considered slope to be the most important factor in predicting the amount of erosion on a site. Steepness of slope and length of slope are closely associated with landform. Certain landforms such as concave and convex slopes erode at different rates and in different parts of the slope (Young 1960; Schumm 1956). Landform was related to trail deterioration in the Canadian Rockies, where alluvial plains were considered the most erosive landforms (Root and Knapik 1972).

5. Use

In addition to the four environmental factors, disturbance by people, animals, or machines can contribute to erosion. Wilderness trails are used by varying numbers of people traveling on foot and with horses, mules, or burros. Cattle and sheep also use some wilderness trails, but not in the study area since earlier in this century. Trail use has often been blamed as the cause of trail deterioration (Snyder 1966; USDI Bureau of Outdoor Recreation 1966).

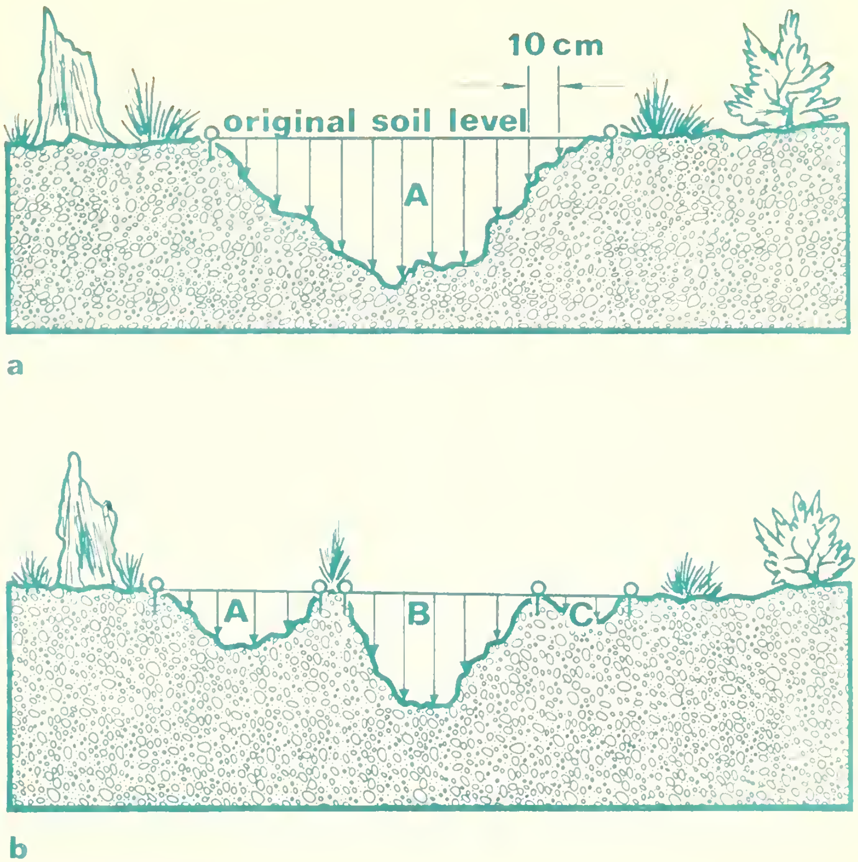
METHODS

Field data were collected from June through November 1972. Seventy sample sites were selected after Forest Service personnel, commercial outfitters, and public groups identified general areas of deteriorated trails. The trails were walked over three times and then the worst sites were selected. The deliberate selection of badly deteriorated sites seemed reasonable for an initial reconnaissance study, but results must be interpreted with caution.

Trail erosion at each selected site was quantified using a cross-sectional area loss index. A taut tape was strung across the trail tread at right angles at the original soil level (fig. 3). The depth of the tread from the tape was then measured at 10-centimeter intervals. The total cross-sectional area was calculated using the formula for the area of a triangle for the end measurements and the formula for the area of a trapezoid for the internal depth measurements. The cross-sectional area loss index can be converted to a soil volume loss by adding a length measurement. The index expresses the impact of manmade trails on the natural environment. One advantage of this quantifying system, as compared to the single depth measurement used by Ketchledge and Leonard (1970) or Dale's (1973) two measurements of depth and width, is that many different types of trails can be compared such as a single tread trail vs. a multiple tread trail. The data can be easily computerized and quickly analyzed.

At each site, depth of soil horizons, trail grade, side slope, aspect, and elevations were recorded. Microclimate was not directly classified but was represented by aspect and elevation. Aspect and elevation influence formation and melting of snowbanks that supply the moisture that causes trail erosion in many situations (Root and Knapik 1972). Vegetative habitat type (discussed below) also reflects general climatic

Figure 3.--Cross-sectional area loss index = A + B + C. The cross-sectional area loss index is a method by which trail erosion can be quantified. Trails of various configurations (3a, 3b) can be compared using this method.



characteristics. Landforms at each site were classified into four broad categories based on origin: (1) Alluvial Erosional; (2) Alluvial Depositional; (3) Glacial Erosional; and (4) Glacial Depositional. The landform types making up each category are:

Alluvial Erosional

concave slope
streambank
ridgetop
gully
saddle
truncated slope
rock outcrop

Alluvial Depositional

slump toe
colluvial slope
landslide
colluvial cone
alluvial-colluvial fan
alluvial slope
stream terrace
flood plain

Glacial Erosional

nivation cirque
cirque wall
ice steepened wall

Glacial Depositional

lateral moraine
recessional moraine
edge moraine
glacial valley train
compacted (indurated) till
glacially eroded valley slope

Parent material was noted. Soil properties can be predicted through identification of the parent material. Parent material also has been related to the erosiveness of soils. For example, trails placed over loessial soils were found to be more erosive than nonloessial soil in the Canadian Rockies (Root and Knapik 1972). Yamamoto and Anderson (1967) used parent material to predict soil erosiveness in Hawaiian soils.

The Daubenmires' (1968) vegetative habitat type approach was used to classify vegetation at sample sites. The closely related habitat types grand fir-*Pachistima (Abies grandis-Pachistima myrsinites)* and western redcedar-*Pachistima (Thuja plicata-Pachistima myrsinites)* were combined. Finally, Ranger District personnel categorized trail use as light, medium, or heavy. In the absence of use records, these classifications were informed judgments. Light use was defined as less than 50 travelers per year; medium, 50 to 125; heavy, over 125.

Sample size was inadequate for linear multiple regression. Instead, the measured variables (for example, elevation, trail grade, etc.) were correlated with the cross-sectional area loss index for the sampled sites within each stratum (for example; for trail slope within landform strata or classes.) Averages were also calculated for each category of the various factors.

RESULTS AND DISCUSSION

Aspect, elevation, and trail grade had variable correlations with trail deterioration (table 1). Deterioration in relation to parent material, landform, vegetative habitat, and use are discussed in more detail in the following sections. Depth of soil horizons had no apparent correlation with trail deterioration. Soils in the Selway-Bitterroot Wilderness were extremely variable; for example, loess and ash have been deposited over a variety of residual soils. More specific data need to be obtained on the relationship of soil horizon to trail degradation.

In addition to entrenchment caused by erosion, two other major types of trail deterioration were identified: bogs caused by perched or high water tables, and landslides caused by trails being constructed on unstable, oversteepened slopes. The area loss index does not represent these last two types of deterioration, and therefore they will be discussed in a qualitative way.

PARENT MATERIAL

Parent material was considered to be the original, weathered aggregates from which the soil formed. Soil material from horneblende gneiss appeared to be subject to more severe trail deterioration than the other parent materials (table 2), although biotite granite is by far the most common parent material for the sample deteriorated sites. Ash and loess were expected to be the most erodible materials, but the actual trail deterioration in these parent materials was relatively low. This could be a result of the trail depth being controlled by the residual soil over which ash and loess were blown. The ash and loess often were observed to have eroded down to the residual soil, which had then eroded to various depths. Trail deterioration in ash appeared to be highly correlated with trail grade. "Accumulation and retention of materials such as loess and ash indicate a very stable, nonerosive surface condition; therefore these sites do not erode as a result of natural site qualities.[2]

[2]Personal communication with Professor Ray Gilkeson, Department of Soils, Washington State University, Pullman. January 1974.

Table 1.--*Cross-sectional area loss related to vegetative habitat types*

Habitat type	Number of samples	Mean area loss	Mean trail grade	Correlations with area loss			
				Side-slope	Trail grade	Elevation	A
		Cm^2	*Percent*	- - - - *Correlation Coefficient* -			
Subalpine fir-*Pachistima*	5	7,880	13.4	0.11	0.84*	-0.28	
Whitebark pine-Subalpine fir	7	6,875	25.0	.25	- .09	- .11	
Ponderosa pine-Bluebunch wheatgrass	5	6,230	25.8	.01	.93*	- .10	
Subalpine fir-*Pachistima*--*Menziesia* phase	6	5,855	14.3	- .26	- .71*	- .30	
Grand fir (western redcedar-*Pachistima*	13	5,837	13.4	- .23	.25	.01	
Subalpine fir-Beargrass	25	5,158	25.2	.17	.29	.39*	
Douglas-fir--Ninebark	3	4,703	29.0	.70*	.99*	.56*	

[1] Asterisk (*) indicates a 10 percent level of significance which means that there is only 10 percent or smaller chance that the correlation in fact does not differ from zero. Simila correlation coefficients are available for tables 2, 3, and 4 in the thesis "Selway-Bitterro trail deterioration study." A high correlation value means a greater association of that fa with trail deterioration.

Table 2.--*Trail cross-sectional area loss related to parent material*

Parent material	Number of samples	Mean area loss[1]	Mean trails grade	Mean elevation
		Cm^2	*Percent*	*Feet*
Ash	4	4,902	21	6,500
Mica schist	5	5,442	19	2,520
Loess	12	5,448	26	6,300
Biotite granite	29	6,388	16	5,130
Granite gneiss	3	6,463	23	5,180
Horneblende gneiss	7	6,841	28	6,580

[1] 1,000 cm^2 equal about 158 in^2.

Table 3.--*Trail cross-sectional area loss as related to landforms*

Landform type	Number of samples	Mean area loss	Mean trail grade	Mean elevation
		cm^2	*Percent*	*Feet*
Glacial Depositional	15	5,365	12	4,100
Glacial Erosional	8	5,545	30	6,610
Alluvial Depositional	23	5,506	19	4,830
Alluvial Erosional	23	6,450	24	5,350

LANDFORM

Three of the landforms had nearly identical mean area losses. Alluvail Erosional landforms had a greater average area loss than the other three landforms (table 3). Many factors interact to create the total cross-sectional area loss. For example, the Glacial Erosional category had very light use and well-drained soil, but a very steep trail grade (30 percent) caused deterioration. The Glacial Depositional category had a fairly gentle grade (12 percent), but heavy use along with a high water table created an equal amount of trail deterioration.

Field observations suggested that landform categories probably were too generalized, and that some of the types within each class were quite different. For example, the mean trail grade in the Glacial Depositional category was 12 percent, but Glacial Valley Train, a landform in the Glacial Depositional category, began to erode severely at only a 4 percent grade. Glaciated alpine valleys in the Glacial Depositional category were associated with bogs and compacted till. Compacted till occurs when gravel has been compressed into an impermeable hardpan by the weight of a glacier. Trail construction brings subsurface drainage to the surface, which accelerates damage (fig. 4). Each of these landforms is in the Glacial Depositional category, but each has separate trail conditions and management problems and should be managed differently.

Oversteepened concave slopes can occur in both Alluvial Erosional and Glacial Erosional categories. Landslides or mass failure of trails in these landforms present a unique and difficult trail management problem as compared to the usual entrenchment in Alluvial Erosional and Glacial Erosional categories. Steep side slopes (trail affected by landslides examined had sideslope from 78 to 99 percent) appear more critical than trail grade in causing trail deterioration in these landforms.

VEGETATIVE HABITAT

Vegetative habitat type is one of the most promising bases for predicting trail deterioration. Each habitat type can have unique trail deterioration problems such as trail grade, type of deterioration, period of use, or a combination of these factors. For example, there was a high degree of correlation between trail grade and area loss within most habitats (table 1). Yet, each habitat type had a different threshold at which trail grade induced serious erosion.

Habitat type is an expression of moisture and soil-related factors. The *Menziesia* phase of the subalpine fir-*Pachistima* habitat type had a finer soil texture and was more moist than the *Pachistima* phase of that habitat type. Deep, single-tread entrenchment occurred at sample sites in the *Menziesia* phase; multiple-tread entrenchment

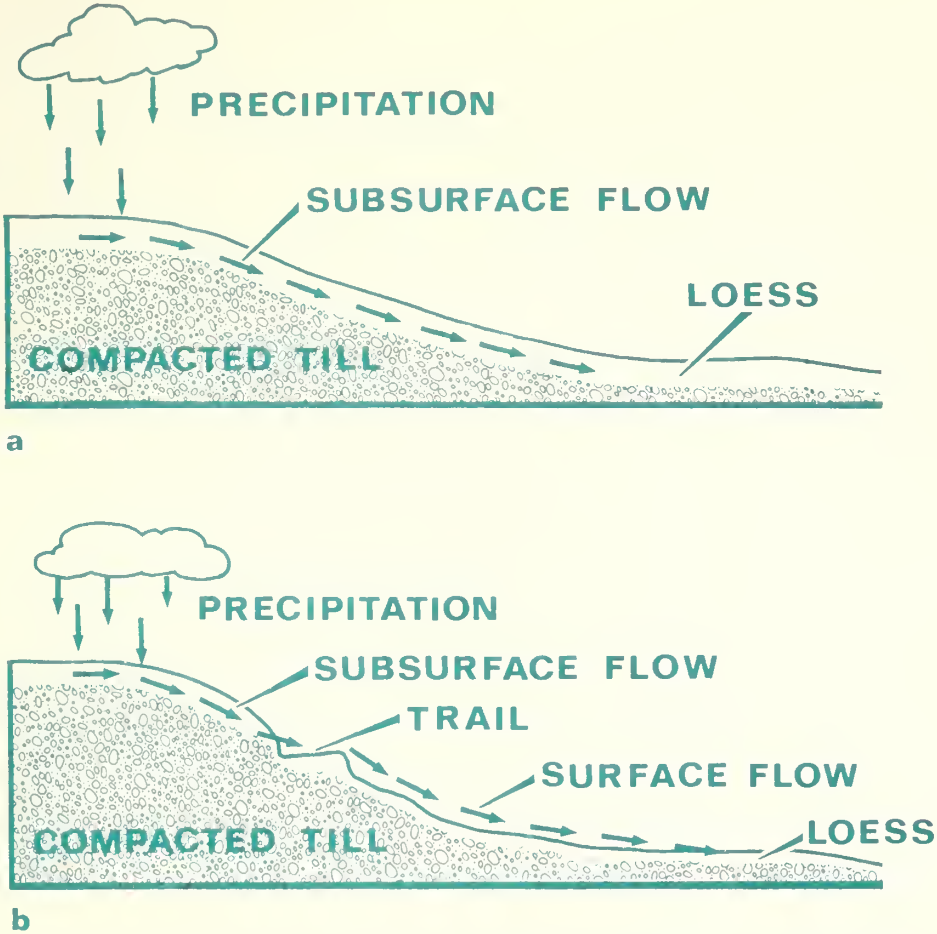


Figure 4.--Building trail on compacted till can interrupt normal subsurface flows (4a) and cause accelerated channel erosion (4b).

occurred in the *Pachistima* phase. High or perched water tables (a factor indicating bog formation) can be associated with the western redcedar habitat types. Field observations suggest that the western redcedar-*Pachistima* habitat type will form bogs while the wetter western redcedar-ladyfern habitat type will form an entrenched trail.

The negative correlation coefficient (table 1), which suggests that as trail grade increases deterioration decreases in the subalpine fir-*Pachistima (Abies lasiocarpa-Pachistima myrsinites)* habitat type, is an anomaly. It may be the result of trail deterioration occurring on areas of compacted till with a loess cap, which have gentle grades compared to the other subalpine fir-*Pachistima* habitat types. In the whitebark pine-subalpine fir type even a gentle slope appeared to be enough to promote active erosion of the ash cap. Sample size in both cases is also small.

TRAIL USE

Amount of use was less strongly and consistently related to deterioration than expected. Table 4 indicates that low-use trails (which were very steep) eroded most severely. High use results in trail damage, especially if perched and high water tables are present. On gentle slopes, little damage would result even with high use on the well-drained sites; poorly drained sites would show greater damage with much less use. Medium use on medium grades has the least cross-sectional area loss. One possible explanation is that medium use may compact the tread enough to inhibit erosion.

Table 4.--*Trail cross-sectional area loss related to use*

Use category	Number of samples	Mean area loss	Mean trail grade	Mean elevation
	No.	*cm²*	*Percent*	*Feet*
High	26	5,983	15	4,550
Medium	24	4,956	22	5,240
Low	19	6,959	25	5,490

It is possible that, as is true for campsite deterioration (Frissell and Duncan 1965; LaPage 1967; Merriam and others 1973) the first, limited use may cause the greatest amount of damage, followed by much slower deterioration with continued, heavier use. Removal of the vegetative cover creates the potential for trail deterioration. Maintenance, usually concentrated on high- and medium-use trails, should also be considered. A trail system with the same amount of use throughout still would have variable amounts of deterioration dependent on site factors. Trail location might be more important than use in causing deterioration of trails. In any event, the role of use in causing trail deterioration is anything but simple and direct.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The study indicated that vegetative habitat, landform, and trail slope are factors importantly related to trail erosion. Aspect, elevation, use, and parent material have variable relations and should be further examined. Soil horizons had no apparent relationship to trail deterioration. A high or perched water table caused trail deterioration in the form of bog formation. This is an easily defined factor which is readily identifiable in the field. High water tables are associated with layering of the parent materials, position on the landform, and vegetative type. Mass failure of trails was associated with steep, convex sideslopes, and vegetative habitat type.

Use, generally blamed in the literature and by management personnel as the factor causing deterioration, was not shown to have a high correlation with trail deterioration. There are two possible reasons: (1) trail slope was highest in low use areas and lowest in high use areas; and (2) maintenance tends to be emphasized on high use areas. The data suggest, however, that use is less important than site in causing trail deterioration.

Resource management can solve many of the problems of trail deterioration. Deterioration is not the inevitable result of increasing use. Management thus could increase biological carrying capacity by avoiding or minimizing limitations imposed by site factors. However, wilderness objectives require protecting both natural conditions and providing visitors with outstanding opportunities to experience solitude. If user impacts on natural conditions (at least on trails) can be managed, then the problem of social carrying capacity (the quality of the visitor's experience) would become critical.

Figure 5.--On some biophysical units, trails erode even at low grades.

BIOPHYSICAL UNITS

Managers need a concept on which to base trail management guidelines. One promising approach is the combining of landform and vegetative habitat into "biophysical units" that express the forces that create the potential for deterioration in a specific environment. For example, critical trail grade seems to vary greatly between different landforms and vegetative types. General guidelines based on an entire forest, region, or agency are not sensitive to varying environmental conditions. For example, the Forest Service Manual[3] states an overall 30 percent grade limitation on trail construction in wildernesses. Many of the trails in the Selway-Bitterroot Wilderness showed excessive deterioration at only a 15 percent trail grade. On some biophysical units trails steeper than 30 percent could be constructed without inducing erosion. In one habitat type, western redcedar-ladyfern Glacial Valley Train, even a 5 percent grade produced serious erosion (fig. 5).

The biophysical units can be mapped. Each unit should contain a description of soils, vegetation, and landforms. Limitations such as period of use can be described. The type of trail deterioration found in that biophysical unit would be identified. Then each unit would have standards for location, construction, and maintenance of trails. Although trails are emphasized in this paper, it should be noted that the concept of biophysical units could be used to manage campsites, too. Three examples of

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[3]USDA Forest Service Manual, 2300 R-1 Suppl. 35 and 41, 1970 and 1971, respectively.

biophysical units in the Selway-Bitterroot Wilderness and tentative trail management guidelines are presented below.

1. Western redcedar-ladyfern, Glacial Valley Train

The vegetation in this habitat is dominated by western redcedar. Ferns are more plentiful than in the western redcedar-*Pachistima* habitat type. Western redcedar-ladyfern are small enclaves within the western redcedar-*Pachistima* vegetative types.

The soils appear to be finer textured than in the western redcedar-*Pachistima*.

The parent material was transported by the valley glacier. There is a high water table and lateral subsurface drainage. Overland flow appears to be more extensive than in western redcedar-*Pachistima*.

The landform is glacial valley train. Located in valley bottoms, glacial valley train is a result of valley glaciation. The slope ranges between 0 and 7 percent.

Trail damage occurs as entrenchment.

Trails should not be built on this enclave. Trails can be routed around the area. If trails are built, planking or corduroy should be used.

2. Subalpine fir-*Pachistima* Over-Steepened and Concave Slopes.

Subalpine fir is the dominant tree in this habitat type. Other overstory species include Engelmann spruce (*Picea engelmannii*), Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and larch (*Larix occidentalis*). The understory is varied and ground cover is moderate. Roses (*Rosa* spp.) are likely to become more numerous close to the trail while strawberries (*Frageria* spp.), violets (*Viola* spp.), and twinflower (*Linnaea borealis*) usually decrease in numbers. There is a *Menziesia ferruginea* phase of this habitat type.

The soils are relatively deep sandy loam that is saturated with water in the spring and is moist most of the year.

The concave, oversteepened slopes are a result of an active erosion process, either glacial or alluvial. The head of the concave slope is more actively eroding than the base. The oversteepened slopes often are above an actively eroding stream. The side slopes range between 70 and 99 percent.

Trail deterioration occurs in the early spring. The first signs of deterioration are cracks along the trail. The cracks accelerate the overloading of the mantle by increasing the water flowing into the soil. Then mass failure occurs, as that section of the trail slips out and downslope.

In this biophysical unit, trails should not be built where the side slope is greater than about 75 percent. Trails should be located well above the heads of these areas.

3. Subalpine fir-*Pachistima* Compacted Till.

The vegetative characteristics are similar to those in the subalpine fir-*Pachistima* Alluvial Erosional.

The soils are highly layered. A loess layer lies over compacted till, which is impermeable to water. Subsurface lateral drainage occurs on the valley side slopes to the valley bottom and emerges at the base of the slope.

"The loess cap is highly erodible especially when the slope hydrology is changed, such as by the construction of a trail where the compacted layer is disturbed by trail construction or presence. This brings subsurface water to the surface, accelerating surface erosion. Also, any disturbance vertically along the slope accelerates surface erosion."[4]

The soil is moist throughout the season except from mid-July to the end of August.

Compacted till occurs on the high glaciated valleys in the Selway-Bitterroot Wilderness. Although the till is stable, the loess cap is highly erodible.

Trails become entrenched down to the compacted till. The tread often has boulders in it. When a trail is constructed on a side slope, the subsurface drainage emerges as springs on the trail. The water becomes a virtual stream eroding the trail.

It is difficult to build trails through this biophysical unit because precaution has to be taken not to interrupt the subsurface drainage. It is best to locate trails high on the valley walls and avoid the base of the hill or the valley bottoms. Water brought to the surface should be countered by placement of water bars and rock culverts.

IMPLICATIONS FOR TRAIL MAINTENANCE AND RELOCATION

Trail relocation is a major approach to trail management. Most trails now in use were not designed for current management objectives. Where feasible, many of these trails should be relocated to serve present and future needs with less resource damage. This program would be implemented over a period of years.

Detailed records of trail maintenance and costs by locations would enable the manager to analyze costs of trail construction on each biophysical unit and help in selecting the least expensive unit on which to locate a trail within minimum resource damage.

A quantitative periodic record of trail conditions would help determine future trends and guide maintenance and redesign efforts. A trail crew could be quickly trained to record the area loss index at intervals along trails.

Professionals who now participate in major trail construction projects also need to be included even on minor trail relocation. Professional soil scientists, hydrologists, plant ecologists., and geologists who should map the biophysical units and write management guidelines might recommend not to build trails on that unit.

Preventive maintenance is important; poorly maintained trails promote greater trail deterioration. For example, multiple trail treads might be caused by hikers or livestock walking out of the tread to avoid boulders or other obstructions. Water bar placement and maintenance can prevent the channeling of water that erodes the trail tread.

FUTURE RESEARCH

Future research on trail deterioration is needed on both the social and the physical aspects of the problem, which are interrelated.

In the Selway-Bitterroot Wilderness, a study similar to the one reported here, but covering less deteriorated trail sites, is needed. There is also a need for a larger sample of the deteriorated sites. The new study could include completion of the bio-

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[4]Personal communication with Mel Bennett, Hydrologist, Clearwater National Forest. January 1974.

physical unit map and development and testing of trail management guidelines based on the biophysical concept. Extensive sampling within each biophysical unit is needed. Economic analysis of trail construction methods and costs within each unit also would be valuable.

Studies are needed in areas having vegetative communities and geologic formations other than the highly erosive Idaho Batholith. This research would also help determine the feasibility of the methods on a large scale.

Soil characteristics such as infiltration rates, cobble content, and texture that were not included in this study might be related to trail deterioration. Length of slope is another omitted, possibly important factor. A study of these factors, aimed at producing guidelines for the manager, would be useful. For example, a table relating soil texture and trail grade to deterioration could define needed water bar spacings. Another possibility is a table relating trail damage to soil moisture content which would help the manager decide when to limit or prohibit use on a particular trail to control damage.

Trail systems are one of the major marks of man on wilderness. They strongly influence use patterns and visitor experiences. Research and improved management of trails could produce many important benefits.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 677-096/47 REGION NO. 8

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507 – 25th STREET, OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-194

April 1975

SPONTANEOUS AND PILOTED IGNITION OF PINE NEEDLES

Dwight S. Stockstad[1]

ABSTRACT

*Spontaneous and piloted ignition of ponderosa pine (*Pinus ponderosa *Laws.) needles were investigated in an isothermal atmosphere. Four levels of sample moisture content were tested and minimum heat flux intensities required to produce ignition, times to ignition, and surface temperatures at time of ignition were recorded. Piloted ignition occurred at lower flux intensities and in less time than did spontaneous ignition. A significant difference in delay time to ignition was found to exist for sample moisture contents above 7.7 percent.*

OXFORD: *431.5*

KEYWORDS: *forest fuel ignition, ignition, pilot ignition, spontaneous ignition, pine needle ignition*

Many workers have studied the ignition and pyrolysis of cellulosic materials (Thomas and others 1958; Simms 1960, 1961, 1963; Martin 1963; Akita 1959; Koohyar and others 1968; Wesson and others 1971), but their research has not furnished needed information about ignition of forest fuels. Fine forest fuels--needles, leaves, twigs, grass, and lichens--are primarily responsible for the spread of forest fires. Ignition temperatures of these fuels are necessary if the rate of fire spread is to be accurately predicted by such fire-spread models as that advanced by Rothermel (1972). The relationship of ignitability of forest fuels to their physical properties, proposed by Anderson (1970), must also be verified by experimental data before it can be used reliably to appraise the fire potential of forest fuels.

Ponderosa pine (*Pinus ponderosa* Laws.) needles are an important fine forest fuel in the Western United States. Cast needles greatly influence the rate of fire spread on the ground and form a needle drape in the living tree that contributes greatly to fire crowning.

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[1]Stationed in Missoula, Montana, at the Northern Forest Fire Laboratory.

A study of ignition properties of fine forest fuels undertaken at the Northern Forest Fire Laboratory pointed up this need for more specific information on pine needles. The results of this portion of the study are reported in this paper.

OBJECTIVES AND PROCEDURES

The objective of this study of pine needles was to measure (1) the time required for ignition to occur, and (2) the surface temperature at the onset of ignition. The Stockstad-Lory ignition furnace (Stockstad and Lory 1970; Stockstad 1972, 1973) was used for all testing. Both spontaneous and piloted ignition were studied using 1- by 0.076-inch needle sections.

The sample temperature was measured by a 3-mil platinum versus platinum 10-percent rhodium thermocouple placed on the forward end of the sample. The ignition chamber temperature was measured by a similar thermocouple in the immediate vicinity of the sample thermocouple (Stockstad 1972). Both thermocouples were connected to a recorder and their output plotted against time.

Uniform maximum-diameter sample size was obtained by passing pine needles through a 0.076-inch "go-no-go" gage. Uniform sample length was obtained by cutting sections from needles of desired diameter with a miniature saw driven by a modified high-speed hand tool.

All samples were kept at ambient air temperature of 22° to 24°C prior to testing. Time required for a sample to exhibit stages of glowing or flaming ignition was recorded. Sample temperature was also recorded during this period. The temperature at the time of exothermic reaction or flaming was defined as the ignition temperature.

Four levels of moisture content (4.9, 7.7, 12.5, and 33.1 percent) were studied. Moisture contents were obtained by placing test sections in conditioning cabinets containing saturated salt solutions (Schuette 1965). Twenty replications were made at each moisture level for both spontaneous and piloted ignition at every furnace temperature used.

Moisture content determinations were made on an ovendry weight basis by using both the conventional ovendry method and the vacuum ovendry method. In both methods, dry weight was subtracted from the original weight to give the weight of water present in the original sample. This figure was then used to calculate the moisture percentage.

The minimum furnace temperature used in the testing program was that at which no ignitions were observed in 20 trials at each moisture content. Furnace temperature was then raised 5° to 10°C and another series of 20 tests observed. This procedure was repeated until a furnace temperature was reached at which 100 percent of the samples ignited.

Several points on the thermocouple traces from a spontaneous ignition test were considered in the analysis (fig. 1). The point at which the sample temperature trace crossed and exceeded the ignition chamber trace was considered to be the beginning of the exothermic reaction. The second significant change in the sample trace was the point where the exothermic reaction increased in intensity resulting in an abrupt rise in the temperature of the sample. This point was considered to be the time and temperature at which the spontaneous ignition process would continue to the end result--visible glowing. An event marker activated by the test operator indicated the time and temperature at which visible glowing was observed. Tests indicated that operator reaction time was approximately one-half second; so this correction was subsequently applied to determine actual glowing ignition time and temperatures.

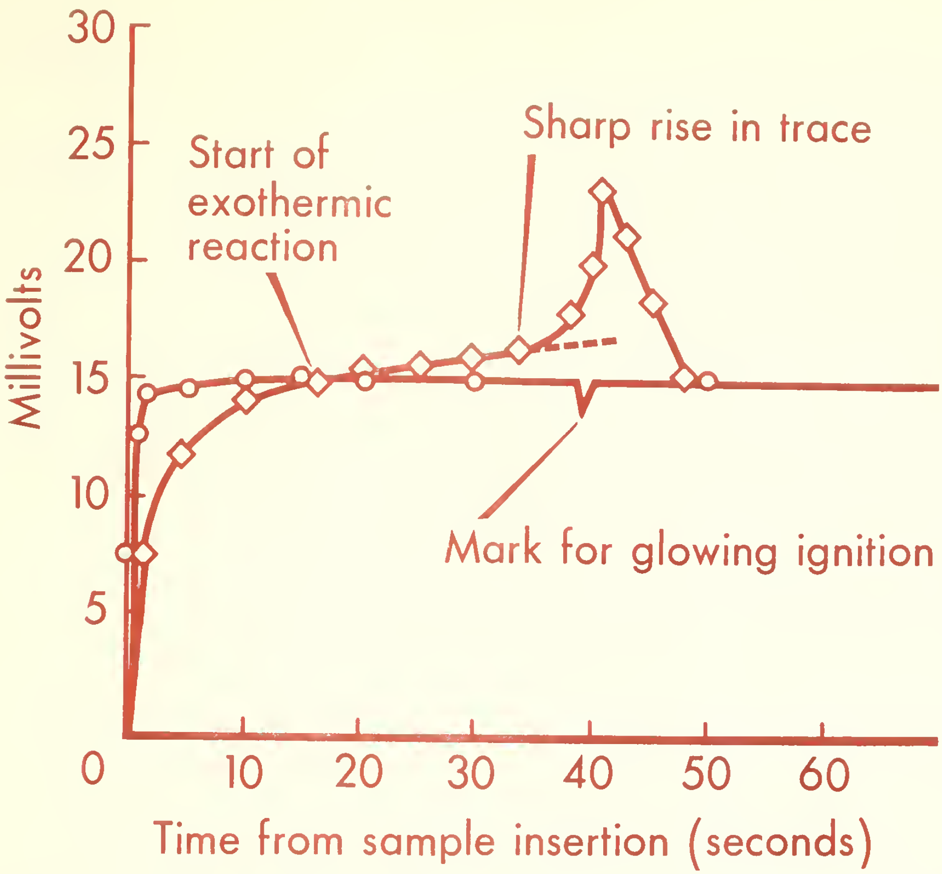

Figure 1.--Sample (◇) and ignition chamber (o) thermocouple traces from a spontaneous ignition test of a 1- by 0.076-inch section of ponderosa pine needle.

Pilot ignition tests were conducted in the same manner as spontaneous ignition tests, except for the introduction of a pilot flame (Stockstad 1972). Pilot ignition usually occurred at temperatures below actual furnace temperature; therefore, the beginning of the exothermic reaction, if one occurred, was not determinable by the previously described criteria. The point at which flaming ignition took place was marked by an abrupt, nearly vertical rise in the trace. An operator-activated event marker was not necessary for the pilot ignition testing.

PREDICTION OF HEATING RATES

Calculations were made to determine the heat transfer coefficients existing in the furnace during heating of the pine needle sections. Heating curves were calculated for three representative furnace temperatures, 360°, 390°, and 425°C. Values from these curves were later used to determine the total heat flux necessary to produce ignition. The assumption was made that the pine needle section would possess properties similar to those of a cylinder in parallel flow. Based on this assumption, the chart plotted by Giedt (1957) was used to obtain values for the Fourier number needed in the calculations.

Formulas used in the calculations were:

$$\theta = \frac{t_o - t_f}{t_i - t_f} = \text{a dimensionless temperature ratio} \tag{1}$$

$$N_{Fo} = \frac{\alpha\tau}{r_1{}^2} = \text{Fourier number} \tag{2}$$

$$N_{Bi} = \frac{K}{hr_1} = \text{Biot number} \tag{3}$$

where

t_o = sample temperature, °F at time t

t_f = furnace temperature, °F

t_i = ambient temperature, °F

τ = time from insertion of sample

$h = h_r + h_c$ = total heat flux for furnace at any given temperature

where

h_r = radiant flux and h_c = convective flux

r_1 = radius of pine needle = 0.038 inch

K = thermal conductivity of pine needle = 2.01×10^{-5} Btu/s-ft, °F (Byram 1952)

α = thermal diffusivity of pine needle = 1.73×10^{-6} ft^2/h, which was calculated from:

$$\alpha = \frac{K}{\rho C_p}$$

where

ρ = 35.6 lb/ft^3 (Brown 1970)

C_p = 3.27×10^{-1} Btu/lb (Byram 1952).

Assuming various sample temperatures between 38° and 424°C and furnace temperatures of 360°, 390°, and 425°C, τ was calculated and resulting values were tabulated in appendix table 1. The values for the 390°C furnace temperature are plotted in figure 2. The curve resulting from the actual heating of a needle section is also plotted in this figure.

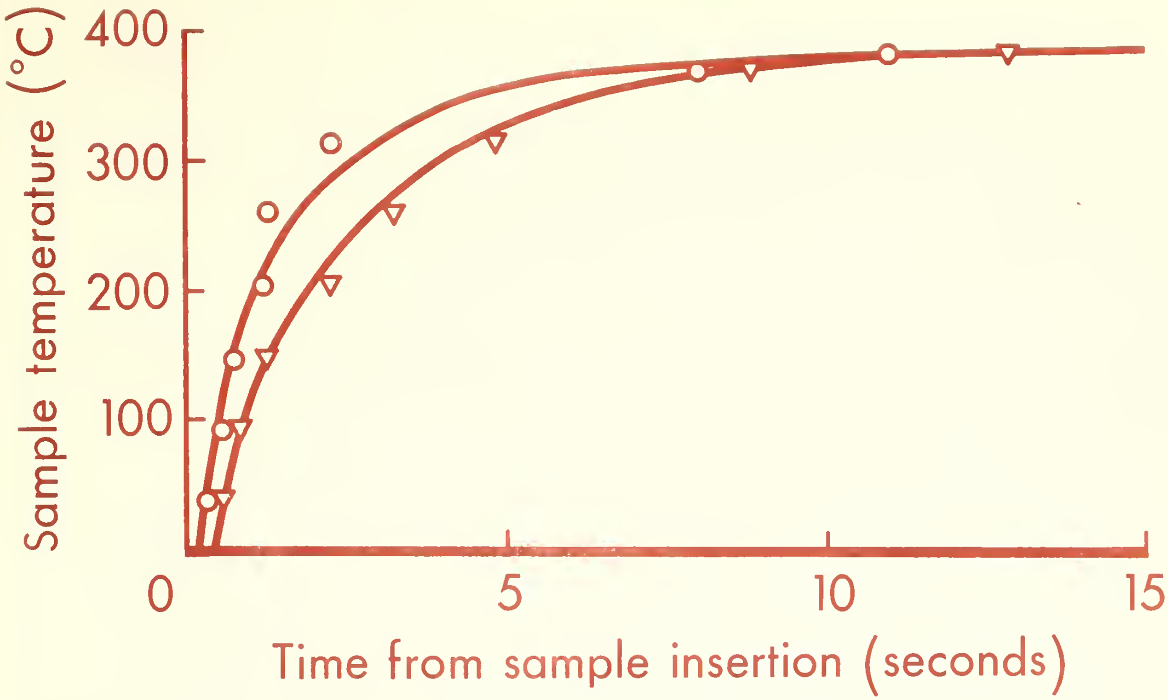

Figure 2.--Calculated (△) and actual (o) time-temperature history of a 1- by 0.076-inch section of ponderosa pine needle at moisture content of 7.7 percent during spontaneous ignition at a furnace temperature of 390°C.

In all cases, the actual heating rate was faster than the calculated rate. A possible explanation could be the increase in absorption of radiant heat flux by the needle section as the needle darkened during the heating process. The heating of organic substances undergoing thermal decomposition is not a simple thermodynamic process; consequently, the use of a single Fourier number may not be applicable as it is for a metal cylinder. It seems likely that minor exothermic processes might begin relatively early as the sample is being heated, thereby contributing to a temperature rise more rapid than would be expected for inorganic materials. The use of a single value for the heat transfer coefficient existing at a given furnace temperature would also account for some of the disparities between the curves.

RESULTS

The results of the 720 spontaneous ignition tests and the 880 pilot ignition tests are given in appendix tables 2 through 7.

The minimum furnace temperature at which spontaneous ignition occurred was 365°C. A furnace temperature of 390°C was needed to produce spontaneous ignition at all moisture contents tested. A furnace temperature increase of 10°C from 380° to 390°C increases the probability of ignition from considerably less than 50 to 100 percent.

Figure 3 shows the relationship between the time required for the ignition processes to occur and the moisture contents tested at 390°C, the temperature at which 100 percent ignitions were first obtained.

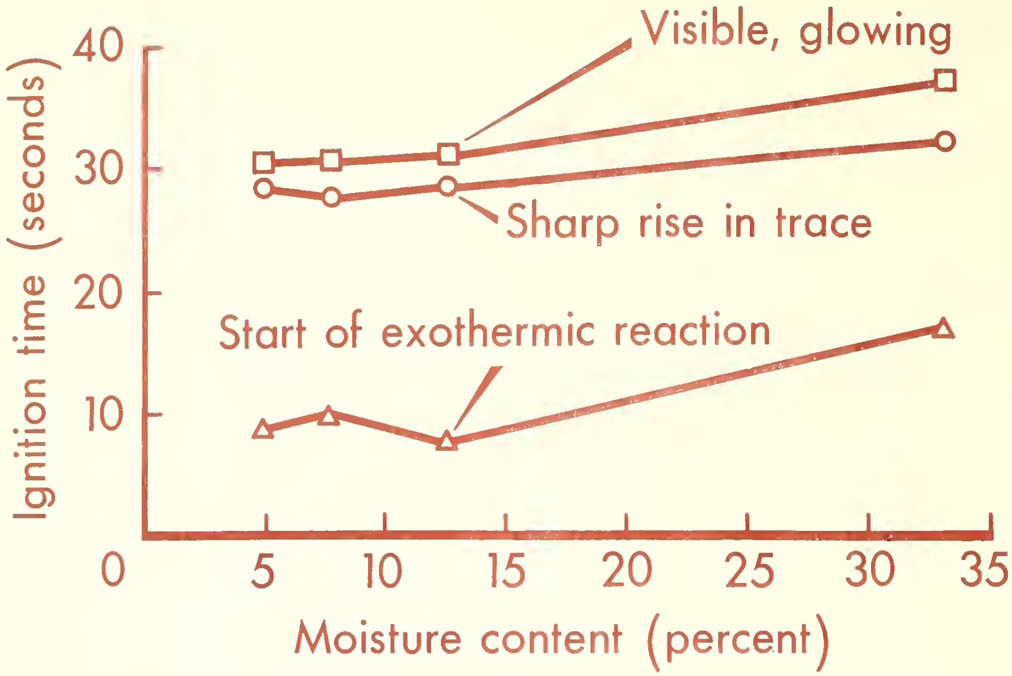

Figure 3.--Ignition time versus moisture content for spontaneous ignition of pine needle sections at a furnace temperature of 390°C.

Analysis of variance showed a significant difference at the 95 percent level of confidence in the times to glowing ignition at the 425° and 480°C furnace temperatures for the fuel moisture contents examined. Further statistical examination using Tukey's multiple range test showed a significant difference in time to ignition between all fuel moisture contents tested, with the exception of the relationship of 4.9 and 7.7 percent moisture contents.

Analysis of variance at the 95 percent level of confidence did not show a significant difference in ignition temperatures obtained for the fuel moisture contents examined.

The minimum furnace temperature at which pilot ignition occurred was 280°C. A furnace temperature of 350°C was needed to produce pilot ignition at all moisture contents tested. The increase in percent of ignitions per each 10°C change in furnace temperature was more gradual than was observed for spontaneous ignition. However, the big increase in ignition percentage still fell within a 30°C temperature range.

Figure 4 shows the average time required for ignition to occur at various furnace temperatures for the four fuel moisture contents tested. Figure 5 shows the relationship between the time required for ignition to occur and the various moisture contents tested at 350°C, the temperature at which 100 percent ignition occurred. Tukey's test indicated a significant difference in time to ignition existed at the 95 percent probability level for all fuel moistures tested above the 7.7 percent level.

Analysis of variance at the 95 percent level of confidence did not show a significant difference in the ignition temperatures obtained.

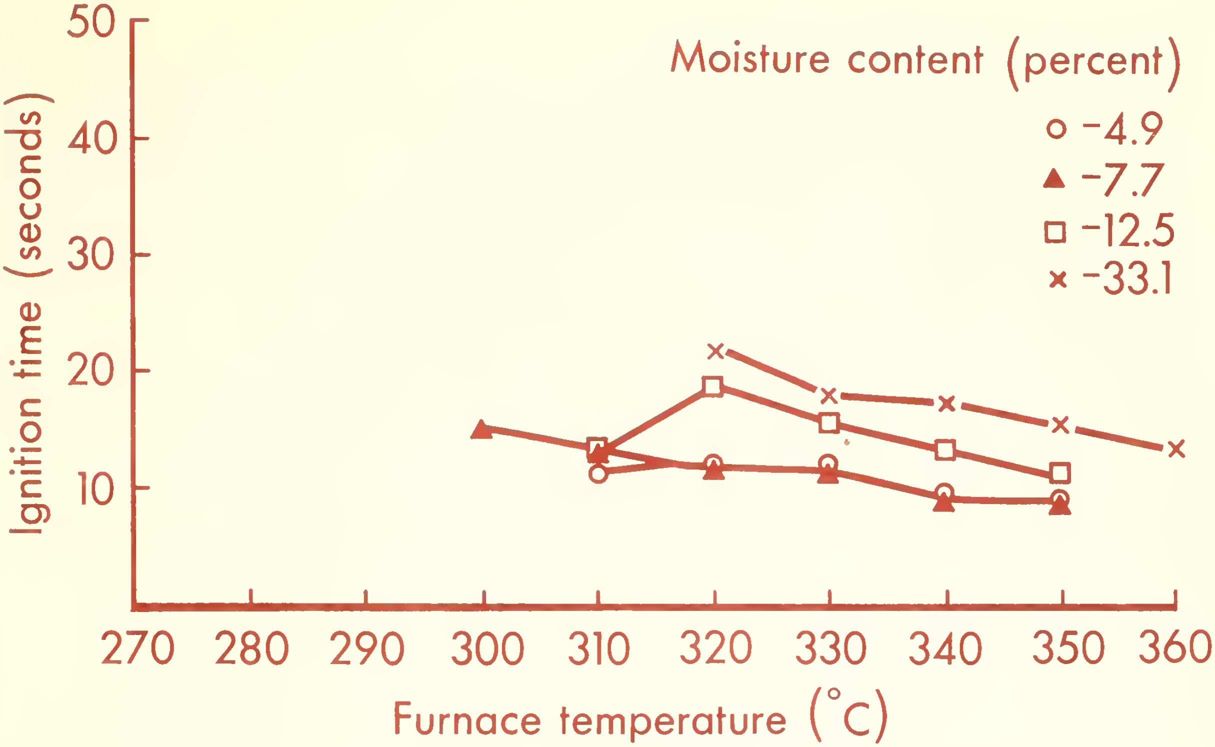

Figure 4.--Ignition time versus furnace temperature for pilot ignition of pine needle sections for various moisture contents.

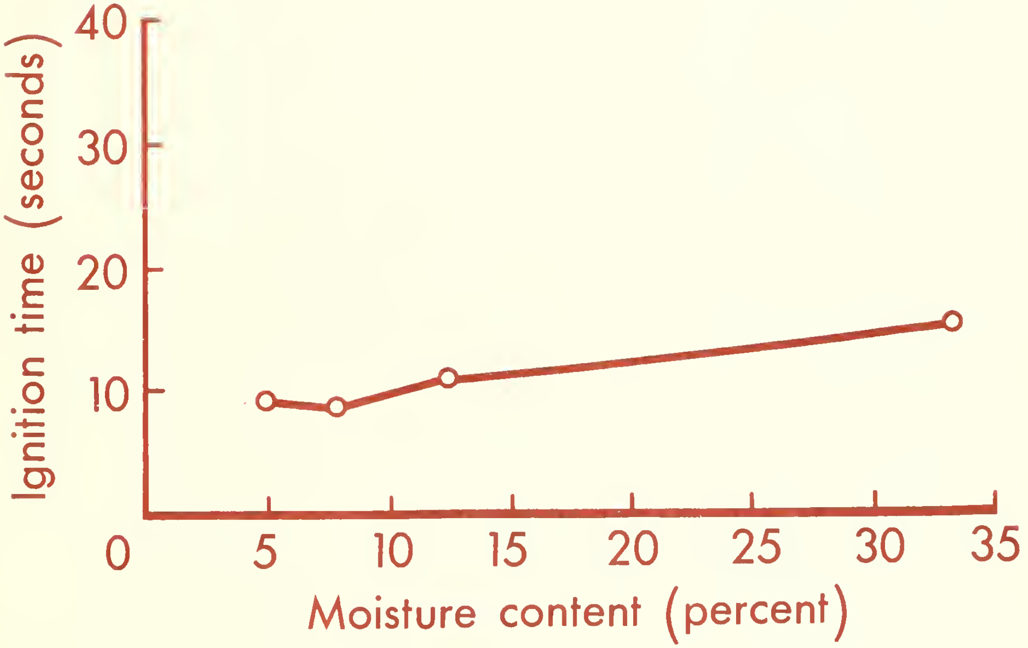

Figure 5.--Ignition time versus moisture content for pilot ignition of pine needle sections at a furnace temperature of 350°C.

DISCUSSION OF RESULTS

The total heat transfer coefficient for furnace temperatures of 375° to 390°C for each sample moisture content was calculated and is tabulated in appendix table 8. The average temperature for each 20 tests at which the exothermic reaction was considered to begin is also listed. From these values, an average heat transfer coefficient and exothermic temperature were determined. The total heat flux needed to produce spontaneous ignition at all moisture contents tested was then calculated to be 6.9 cal/cm^2 or a total of 29.8 calories. By using this value, an average ignition delay time of 13.6 seconds was calculated. The actual average ignition delay time was also 13.6 seconds.

The total heat flux necessary to produce ignition if a pilot flame is present is altered considerably. The total heat transfer coefficient for furnace temperatures of 320° to 350°C for each sample moisture content was calculated and is listed in appendix table 9. Also listed in this table is the average temperature for each 20 tests at which flaming ignition occurred. The average heat transfer and ignition temperature were then determined. The total heat flux necessary to produce flaming ignition was calculated to be 5.1 cal/cm^2, or a total of 19.9 calories. The average ignition delay time was calculated to be 13.3 seconds, compared to an actual average ignition delay time of 13.3 seconds.

Spontaneous ignition occurred at a minimum flux intensity of 0.49 cal/cm^2-s, although 0.53 cal/cm^2-s was necessary before ignition took place at all moisture contents tested. Pilot ignition occurred at a minimum flux intensity of 0.32 cal/cm^2-s; 100 percent of all samples tested ignited at intensities of 0.47 cal/cm^2-s.

CONCLUSIONS

Based on the obtained results, certain general conclusions can be drawn concerning ignition of pine needles when heated to ignition in an isothermal atmosphere. In the absence of a pilot flame, spontaneous ignition will occur at moisture contents up to 33 percent if the igniting agent is capable of producing a heat flux intensity of 0.53 cal/cm^2-s for 13.6 seconds. In the presence of a pilot flame, ignition will occur at moisture contents up to 33 percent if the igniting agent is capable of producing a heat flux intensity of 0.47 cal/cm^2-s for a period of 13.3 seconds.

A significant difference at the 95 percent level of confidence in delay time to ignition was shown to exist for both pilot and spontaneous ignition for needle moisture contents above 7.7 percent. No significant difference at the 95 percent level of confidence was found for moisture contents below the 7.7 percent level. From this, we conclude that the probability of an ignition occurring does not increase at moisture levels below the 7.7 percent level, but does decrease at moisture contents above this level.

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Table 1.--*Calculated and actual time for a pine needle section to reach a given temperature for three furnace temperatures*

Needle section temperature (°C)	Furnace temperature					
	360°C		390°C		425°C	
	Calculated time	Actual time	Calculated time	Actual time	Calculated time	Actual time
	Seconds					
38	0.5	0.5	0.5	0.4	0.5	0.4
93	.9	.8	.9	.7	.6	.5
149	2.1	1.0	1.4	.8	1.0	.8
204	3.0	1.5	2.2	1.2	1.5	1.0
260	4.4	2.5	3.3	1.2	2.2	1.3
316	5.5	5.5	4.9	2.2	3.1	2.1
343	9.6	10.0	[1] --	--	--	--
371	--	--	8.9	8.0	4.7	4.2
385	--	--	12.9	11.0	--	--
399	--	--	--	--	6.2	6.0
413	--	--	--	--	8.0	8.0
424	--	--	--	--	10.8	11.0

[1] No measurements taken.

Table 2.--*Percentage of spontaneous ignitions of pine needle sections at selected furnace temperatures for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture content			
	4.9	7.7	12.5	33.1
360	0	0	0	0
365	0	5	5	5
370	0	10	0	0
375	15	10	45	30
380	20	45	20	25
385	80	80	70	75
390	100	100	100	100
425	100	100	100	100
480	100	100	100	100

Table 3.--*Time to spontaneous ignition of pine needle sections at selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Start of exothermic reaction				Sharp rise in trace				Visual glowing			
	Percent moisture content				Percent moisture content				Percent moisture content			
	4.9	7.7	12.5	33.1	4.9	7.7	12.5	33.1	4.9	7.7	12.5	33.1
	Seconds											
360	[1]--	--	--	--	--	--	--	--	--	--	--	--
365	--	18.0	15.0	21.0	--	57.5	33.5	59.5	--	65.7	38.0	66.0
370	--	18.8	--	--	--	51.8	--	--	--	61.4	--	--
375	15.0	13.0	12.4	18.6	41.0	40.2	40.2	46.9	41.2	45.0	44.1	59.2
380	17.4	16.7	17.5	18.8	46.4	43.1	48.2	41.8	49.4	49.2	52.4	54.1
385	9.4	8.6	8.8	20.3	29.2	22.5	29.6	40.5	31.0	25.9	34.2	44.4
390	8.4	8.8	7.6	17.0	28.7	27.9	28.6	32.1	30.4	30.6	31.0	37.1
425	8.5	8.2	6.9	14.8	15.7	15.7	12.5	17.5	18.1	17.6	14.6	20.1
480	9.1	7.1	8.0	11.7	9.8	8.2	8.6	12.3	11.0	9.5	9.9	13.5

[1] Dashed lines indicate no ignition occurred.

Table 4.--*Temperatures (°C) at time of spontaneous ignition of pine needle sections averaged for 20 tests per furnace temperature and varying moisture contents*

Furnace temperature	Start of exothermic reaction				Sharp rise in trace				Visual glowing			
	Percent moisture content				Percent moisture content				Percent moisture content			
	4.9	7.7	12.5	33.1	4.9	7.7	12.5	33.1	4.9	7.7	12.5	33.1
360	[1]--	--	--	--	--	--	--	--	--	--	--	--
365	--	367	367	361	--	391	396	391	--	426	432	428
370	--	367	--	--	--	384	--	--	--	404	--	--
375	371	372	369	368	393	402	402	402	404	426	422	422
380	378	378	380	379	400	399	409	404	414	421	434	410
385	388	387	382	384	408	421	401	407	430	463	429	428
390	379	378	373	382	407	412	403	401	427	441	425	432
425	403	406	404	420	435	438	435	441	485	482	474	497
480	468	466	467	467	479	478	479	481	548	534	547	562

[1] Dashed lines indicate no ignition occurred.

Table 5.--*Percentage of pilot ignitions of pine needle sections for selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperatures (°C)	Percent moisture contents			
	4.9	7.7	12.5	33.1
270	0	0	0	0
280	0	10	0	0
290	5	0	0	0
300	0	10	0	0
310	5	10	10	0
320	35	45	15	10
330	85	75	70	45
340	85	100	80	85
350	100	100	100	100
360	100	100	100	100
425	100	100	100	100

Table 6.--*Time to pilot ignition of pine needle sections for selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture contents			
	4.9	7.7	12.5	33.1
	- - - - - - *Seconds* - - - - - -			
270	--[1/]	--	--	--
280	--	7.8	--	--
290	3.6	--	--	--
300	--	15.0	--	--
310	11.8	13.4	13.4	--
320	12.0	11.7	18.4	21.8
330	11.4	11.4	15.4	18.0
340	9.1	9.1	13.1	17.3
350	9.1	8.9	11.1	15.3
360	--	--	--	13.4
425	4.8	4.6	6.6	8.5

1/ Dashed lines indicate no ignition occurred.

Table 7.--*Temperatures (°C) at time of pilot ignition of pine needle sections at selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature	Percent moisture contents			
	4.9	7.7	12.5	33.1
270	[1/] --	--	--	--
280	--	251	--	--
290	259	--	--	--
300	--	237	--	--
310	243	251	238	--
320	270	264	263	285
330	291	289	298	303
340	296	292	306	324
350	303	310	313	323
360	--	--	--	325
425	330	319	341	351

1/ Dashed lines indicate no ignition occurred.

Table 8.--*Average heat transfer coefficient (h_t) and temperature at initiation of exothermic reaction during spontaneous ignition of pine needle sections for 20 tests per moisture content at selected furnace temperatures*

Furnace temperature (°C)	Sample moisture content	h_t	Start of exothermic reaction
	Percent	*Cal/cm²-°C*	*°C*
375	4.9	0.021	371
	7.7	.019	372
	12.5	.018	369
	33.1	.026	368
380	4.9	.025	378
	7.7	.024	378
	12.5	.025	380
	33.1	.027	379
385	4.9	.014	388
	7.7	.012	387
	12.5	.013	382
	33.1	.029	384
390	4.9	.012	379
	7.7	.013	376
	12.5	.011	373
	33.1	.025	382
Average of all tests:		.020	378

Table 9.--*Average heat transfer coefficient (h_t) and temperature at flaming ignition during pilot ignition of pine needle sections for 20 tests per moisture content at selected temperatures*

Furnace temperature (°C)	Sample moisture content	h_t	Flaming ignition
	Percent	*Cal/cm²-°C*	*°C*
320	4.9	0.015	270
	7.7	.015	264
	12.5	.023	263
	33.1	.027	285
330	4.9	.015	291
	7.7	.015	289
	12.5	.020	298
	33.1	.023	303
340	4.9	.012	296
	7.7	.012	292
	12.5	.017	306
	33.1	.023	324
350	4.9	.012	303
	7.7	.012	310
	12.5	.015	313
	33.1	.020	323
Average of all tests:		.017	296

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USDA Forest Service
Research Note INT-195

June 1975

WINTER STORAGE AND PACKAGING EFFECTS ON LUCKY PEAK SEEDLINGS

Frank E. Morby and Russell A. Ryker[1]

ABSTRACT

Six species of seedlings from nine different Lucky Peak Nursery seed lots were lifted in November and stored for the winter at both 28° and 33° F in both bag and crate packages. Initial survival and growth of study seedlings planted in the Boise, Payette, Sitgreaves, and Lincoln National Forests were compared with rates for seedlings from the same lots planted after conventional spring lifting. Results indicate that winter storage is generally feasible, but the best packaging method and lifting season differ with species. No advantage was gained by storing seedlings at the subfreezing 28° F temperature.

Several considerations make the feasibility of fall seedling lifting and winter storage important in the area served by Lucky Peak Nursery, Boise, Idaho.

National Forests in Arizona, New Mexico, and southern Utah experience optimal planting conditions in February or early March. Soils then dry rapidly, and prospects for seedling survival quickly decline. Weather and soil conditions at Lucky Peak Nursery seldom permit seedling lifting and delivery before mid-March.

The Boise and Payette National Forests in Idaho are evaluating fall lifting and planting of nursery stock as a means of increasing the efficiency of reforestation programs. Lucky Peak Nursery can regulate soil moisture to provide excellent lifting conditions in the fall, resulting in less seedling root damage than occurs with spring lifting. However, early storms at times prevent the completion of fall planting and some stock must be destroyed.

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If seedlings could be lifted in the fall and successfully stored during winter, some forests could hold unused fall planting stock for spring, other forests could receive trees for planting at the optimal time, and the nursery would have greater flexibility in scheduling lifting operations.

Stock lifted in the spring at Lucky Peak Nursery normally is stored at 33° F. To minimize molding and metabolic activity, others (Hocking and Nyland 1971; Hocking and Ward 1972) have stored trees at subfreezing temperatures. The results indicated that the lower temperature may be better for a long winter storage period, providing the below-freezing conditions do not damage the trees.

Both bags and crates have been used successfully to package spring-lifted stock. We were interested in comparing bag and crate storage to determine if desiccation occurs in crated seedlings at subfreezing temperatures.

The primary objective of this study was to determine if fall-lifted seedlings stored at 28° or 33° F will survive and grow as well as spring-lifted seedlings handled by standard procedures. A secondary objective was to determine if packaging methods (bags, crates) influence the survival and growth of seedlings subjected to the different lifting schedules and storage regimes.

METHODS

In November, 1972, after an oscilloscope trace indicated dormancy, we lifted (fig. 1) 1-0 ponderosa pine (*Pinus ponderosa* Laws.), 2-0 lodgepole pine (*Pinus contorta* Dougl.), 2-0 Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and 3-0 Engelmann spruce (*Picea engelmannii* Parry) from stock scheduled for planting on the Boise National Forest; 2-0 ponderosa and 1-0 western larch (*Larix occidentalis* Nutt.)

Figure 1.—Study seedlings were lifted in November at Lucky Peak Nursery.

Figure 2.--Seedlings were packaged root-to-root in crates.

from stock scheduled for the Payette National Forest; 2-0 ponderosa pine from stock scheduled for the Sitgreaves National Forest, Arizona; 2-0 ponderosa pine from stock scheduled for the Lincoln National Forest, New Mexico; and 1-0 bitterbrush (*Purshia tridentata* (Pursh) DC.) from stock scheduled for the Idaho Fish and Game Department to be planted within Boise National Forest boundaries.

The use of an oscilloscope to determine seedling dormancy is a recent research development. Manuscripts are being prepared describing the technique, which has proven successful in numerous field tests.

Half of each lot of trees and shrubs was packaged in bags and half in crates on the day the seedlings were lifted. Crates were 22-1/2 inches long, 16 inches wide, and 7-1/2 inches deep. A 24-inch strip of Fibreen 200,[2] a waterproofed and fiber-reinforced kraft paper, was used to line the crates. A 1-1/2- to 2-inch layer of clean, well-moistened sphagnum moss covered the paper and alternate layers of moss and seedlings were placed into crates. The seedlings were placed root to root (fig. 2) in the approximate center of the crate. A final 1-1/2- to 2-inch layer of moist sphagnum was placed over the roots of the top layer of seedlings and the waterproof paper was gathered at the ends and rolled tightly. The crates were closed with four wire catches.

The seedling bags were 24- by 11- by 35-inch three-ply kraft paper with an inner layer of polyethylene that forms a moisture barrier. Two large handfuls of well-moistened sphagnum moss were placed in the center of the bottom of the seedling bag. Seedlings were placed in layers with roots over the moss. Two large handfuls of moss were used to cover the roots of the top layer of seedlings. The bag (fig. 3) was closed and rolled tightly to expel the air. The rolled seal was then taped with four strips of 1-inch nylon reinforced tape.

Considerably more sphagnum was used in crate packaging. One thousand seedlings packed in crates weigh 20 to 25 pounds more than equivalent seedlings packaged in bags.

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

Figure 3.--Bags were tightly rolled to expel air.

Half of each lot of packages was placed in refrigerated storage maintained at 28° F. The other half was placed in storage maintained at 33° F. Relative humidity varied between 52 and 69 percent in 28° F storage and between 85 and 92 percent in 33° F storage (fig. 4).

All spring-lifted stock was lifted during the period February 16 to March 28, 1973 (table 1). The lifting was done routinely except that seedlings for the study were taken from seedbed areas immediately adjacent to the fall 1972 study seedling lift areas. Thus, essentially the same soil and site characteristics prevailed for both fall- and spring-lifted seedlings of each stock.

The storage period at the nursery was not the same for all stock. Table 1 indicates both nursery and field storage periods. Because all seedlings for the Boise and Payette National Forests and the Idaho Fish and Game Department were held at the nursery until planting time, the seedlings stored at 28° F were placed in 33° F storage on April 2, and held at that temperature until shipped.

Figure 4.--Packaged seedlings were placed in refrigerated storage at 28° and 33° F.

Table 1.--*Lifting, storage, and planting schedules for seedling lots used in the study*

Cooperator	Species	Age class	Date planted 1973	Fall-lifted: Date lifted 1972	Fall-lifted: Days in nursery storage	Fall-lifted: Days from shipment until planting	Spring-lifted: Date lifted 1973	Spring-lifted: Days in nursery storage	Spring-lifted: Days from shipment until planting
Boise N.F.	Ponderosa pine	1-0	5/8	11/13	171	5	3/28	36	5
Boise N.F.	Lodgepole pine	2-0	5/8	11/13	171	5	3/6	58	5
Boise N.F.	Douglas-fir	2-0	5/8	11/13	171	5	3/7	57	5
Boise N.F.	Engelmann spruce	3-0	5/8	11/13	171	5	3/6	58	5
Payette N.F.	Ponderosa pine	2-0	5/17	11/13	185	0	3/19	59	0
Payette N.F.	Western larch	1-0	5/18	11/13	185	1	2/16	90	1
Sitgreaves N.F.	Ponderosa pine	2-0	5/22	11/6	133	64	3/12	7	64
Lincoln N.F.	Ponderosa pine	2-0	4/4	11/8	100	47	3/13	0	21
Idaho Fish & Game	Bitterbrush	1-0	4/25	11/13	163	0	2/16	68	0

After the seedlings left the nursery, the stock handling, site preparation, and planting procedures and site conditions varied among cooperators. Therefore, the field plantings should be considered as separate experiments for each stock. The experimental design for all was randomized block with three replications. Each plot contained 50 planted seedlings. Selected comparisons among treatment means were made using a sequential method (Snedecor 1956, p. 253).

BOISE STOCK

From May 4 to May 8, 1973, plots for each species shipped to the Boise National Forest were completely cleared to mineral soil using handtools. All stock was removed from the nursery 33° F storage on May 3, 1973, and transported to the planting site. Temperatures within the root zone of the seedlings in the crates held at 36° F during transporting. At the planting site the stock was placed in cool shade, covered with a light colored tarp, and permitted to reach ambient air temperature before auger planting on May 7 and 8, 1973. The planting was done by a team of two augermen and six planters. Fifty 4- by 14-inch holes were bored in each plot ahead of the planters.

The planting site was on granitic soil at an elevation of about 5,000 feet. The ponderosa pine and Douglas-fir were planted on a south aspect, the lodgepole pine on an east aspect, and the Engelmann spruce in a cove.

Approximately three-fourths inch of rainfall was received during and just after planting. The growing season was normal, with little precipitation during July and August. There were no extended periods of hot weather.

First-year survival and growth measurements (table 2) were taken September 11.

Table 2.--*Mean survival and height growth, and statistical significance*[1] *for the four seedling lots planted on the Boise National Forest*

Time of Lifting	Storage temperature	Package	Ponderosa pine: Survival	Ponderosa pine: Height growth	Lodgepole pine: Survival	Lodgepole pine: Height growth	Douglas-fir: Survival	Douglas-fir: Height growth	Engelmann spruce: Survival[2]	Engelmann spruce: Height growth
	°F		*Percent*	*Cm*	*Percent*	*Cm*	*Percent*	*Cm*	*Percent*	*Cm*
Fall	28	Bag	98 a	7.3 a	100 a	9.8 a	75 a	6.3 a	95	4.6 ab
Fall	28	Crate	90 b	5.9 b	88 b	4.0 b	57 b	4.3 b	83	3.4 c
Fall	33	Bag	100 a	7.1 a	100 a	9.6 a	90 a	7.5 a	93	4.7 a
Fall	33	Crate	98 a	6.5 ab	98 a	11.2 a	76 a	7.4 a	99	4.9 a
Spring	33	Bag	98 a	5.3 c	96 a	10.2 a	96 a	3.7 b	97	3.9 bc
Spring	33	Crate	98 a	5.6 bc	100 a	9.4 a	93 a	3.2 b	97	4.4 ab

[1] In each column of the table, all means followed by the same letter do not differ significantly at the 95 percent confidence level.

[2] Analysis of variance revealed no significant differences between treatments for survival, at the 95 percent level, so we chose not to make a comparison between means.

PAYETTE STOCK

During late summer and fall of 1972 the Payette National Forest planting sites were prepared using a medium-size bulldozer with a brush-piling or land-clearing blade. The majority of the site was completely cleared to mineral soil.

All stock was removed from the nursery 33° F storage on May 17, 1973, and transported during the early morning hours in an insulated container. The 2-0 ponderosa pine was removed from the transporting container and placed in cool shade. Trees were auger-planted by a team of one augerman and three planters, alternately planting behind the auger. The auger holes were approximately 4 by 14 inches. The planting site is an east-facing slope with basaltic soils that are 15 to 30 inches deep with some broken rock. The elevation is 5,500 feet. Precipitation during the growing season was below normal and mean maximum temperatures for May, June, July, and August were slightly above normal.

The 1-0 western larch was removed from nursery storage on May 17, 1973, transported to the planting site, and held overnight at approximately 40° F. Trees were auger-planted on May 18. There were six planters in the planting crew. The planting site was on an east-facing, 2-percent slope with granitic soil 18 inches deep. The weather during the growing season was warmer than normal, with less rainfall.

First-year survival and growth measurements (table 3) were taken for the pine on September 6, and for the larch on October 2.

Table 3.--*Mean survival and height growth, and statistical significance*[1] *for the two seedling lots planted on the Payette National Forest*

Time of lifting	Storage temperature	Package	Ponderosa pine: Survival	Ponderosa pine: Height growth[2]	Western larch: Survival[2]	Western larch: Height growth[2]
	°F		*Percent*	*Cm*	*Percent*	*Cm*
Fall	28	Bag	100 a	5.8	95	19.5
Fall	28	Crate	64 b	3.4	99	15.0
Fall	33	Bag	100 a	6.3	93	17.9
Fall	33	Crate	88 a	5.0	98	17.9
Spring	33	Bag	100 a	6.0	97	17.6
Spring	33	Crate	98 a	5.8	96	17.7

[1] In each column of the table, all means followed by the same letter do not differ significantly at the 95 percent confidence level.

[2] Analysis of variance revealed no significant differences at the 95 percent level, so we chose not to make a comparison between means.

SITGREAVES STOCK

The fall-lifted stock for the Sitgreaves National Forest was held in nursery storage at the assigned temperatures until March 19, 1973, when it was removed and shipped in a refrigerated van (33° to 34° F) to the planting site. The spring portion of the stock was lifted on March 12, 1973, and stored at 33° F until it was shipped with the fall stock.

The stock was received at the planting site on March 21, 1973. Trees were stored in a snow cache. No temperature or humidity readings were taken. The planting site was a flat ridgetop with cobbly loam soils. Because of an unusually wet year, planting was delayed until May 21 and 22, 1973. Trees were planted by a crew of three using planting bars. Each crew member planted one block. There was a late, wet spring, summer rains were below normal, and the fall months were dry.

First-year survival and height growth (table 4) were measured September 18.

Table 4.--*Mean survival and height growth for ponderosa pine planted on the Sitgreaves National Forest*[1]

Time of lifting	Storage temperature	Package	Survival	Height growth
	°F		*Percent*	*Cm*
Fall	28	Bag	58	5.2
Fall	28	Crate	70	4.4
Fall	33	Bag	52	3.9
Fall	33	Crate	76	4.0
Spring	33	Bag	62	4.0
Spring	33	Crate	50	3.3

[1] Analysis of variance revealed no significant differences at the 95 percent level.

LINCOLN STOCK

The fall-lifted stock for the Lincoln National Forest was held in nursery storage at the designated storage temperatures until February 16, 1973, when it was removed and shipped on a refrigerated van (33° to 34° F) to the planting site. The stock was received on February 18, and stored in a refrigerated van at 33° to 40° F and 90 percent humidity until planted.

On March 13, 1973, the spring portion of the study stock was lifted, packaged, and shipped via airfreight the same day.

The planting site is on a ridgetop with a slight northeast aspect. Soils are generally dry loam with varying amounts of limestone rock. The elevation is 7,050 feet. The planting blocks were completely scalped of all vegetation before planting. As on the Sitgreaves Forest, planting was delayed until March 30 and April 4, 1973, by wet weather. The planting was done by a six-man crew. A 4-inch auger was used to bore planting holes approximately 4 by 14 inches. During planting there were cold temperatures with high humidities. Moisture received during the growing season was normal for April and May, but less than normal for the balance of the season. Temperature and humidity were normal for the growing season.

First-year survival and height growth (table 5) were measured September 17, 1973.

Table 5.--*Mean survival and height growth, and statistical significance*[1] *for ponderosa pine seedlings planted on the Lincoln National Forest*

Time of lifting	Storage temperature	Package	Survival	Height growth[2]
	°F		*Percent*	*Cm*
Fall	28	Bag	10 c	5.0
Fall	28	Crate	([3])	([3])
Fall	33	Bag	48 b	5.1
Fall	33	Crate	70 ab	5.6
Spring	33	Bag	88 a	5.5
Spring	33	Crate	90 a	5.8

[1] In each column, all means followed by the same letter do not differ significantly at the 95 percent confidence level.

[2] Analysis of variance revealed no significant differences at the 95 percent level, so we chose not to make comparisons between means for height growth.

[3] These seedlings were inadvertently removed from storage and mixed with nonstudy stock.

BITTERBRUSH STOCK

The bitterbrush stock provided for the Idaho Fish and Game Department was planted and measurements were made by Robert B. Ferguson, Wildlife Biologist, Intermountain Forest and Range Experiment Station. It was stored in the same manner as the Boise and Payette National Forest tree seedling stock. The spring stock was lifted and stored on February 16, 1973. All of the seedlings were removed from storage and planted on April 25, 1973. Individual 2- by 3-foot planting plots were scalped using a wheel tractor with terracing blade on a 3-point hitch. Planting was done by four planters using planting spades. The sites were south-facing slopes with granitic soil at an elevation of about 3,200 feet. The growing season was dryer and warmer than normal.

First-year survival was measured September 10, 1973 (table 6). Because of the difficulty in identifying new growth on bitterbrush, first-year height growth was not measured.

Table 6.--*Mean survival and statistical significance*[1] *for bitterbrush nursery stock*

Time of lifting	Storage temperature	Package	Survival
	°F		*Percent*
Fall	28	Bag	70 ab
Fall	28	Crate	44 b
Fall	33	Bag	84 a
Fall	33	Crate	68 ab
Spring	33	Bag	92 a
Spring	33	Crate	98 a

[1] In each column, all means followed by the same letter do not differ significantly at the 95 percent level.

SUMMARY OF RESULTS

There were no significant statistical differences in first-year survival or height growth between crated and bagged spring-lifted trees. This also was true for fall-lifted trees, except for crated trees stored at the subfreezing temperature (28° F). This storage greatly reduced survival and growth of most of the seedling lots tested.

With the exceptions of the crated seedlings stored at 28° F and the ponderosa pine stock planted on the Lincoln National Forest, there were no significant differences in survival between fall-lifted and spring-lifted trees. However, height growth of some stock does appear to be affected by season of lifting. The first-year height growth of ponderosa pine and Douglas-fir was greater for fall-lifted than for spring-lifted trees. Lodgepole pine and Engelmann spruce trees, however, showed almost the same growth for both lifting seasons.

Table 7 presents a ranking according to a scale of arbitrary success values for the various species, lifting seasons, storage temperatures, and packages.

When planting on the Boise and Payette National Forests, we can expect acceptable tree seedling survival when any of the lifting, storage, and packaging techniques studied are used, except fall lifting and storage in crates at 28° F. For bitterbrush, spring lifting should be practiced when possible but, if necessary, seedlings can be lifted in the fall and stored at 33° F in bags.

None of the techniques studied resulted in good survival on the Sitgreaves or Lincoln National Forests. The precise reasons for the poorer survival and growth of these seedlings are unknown. Because they were lifted and handled in the same way as all other seedlings, we assume these trees were in equally good physiological condition when they were shipped from the nursery. However, there were more opportunities for adverse conditions to occur during shipment and local storage than for seedlings shipped to the Boise and Payette National Forests. The elapsed time from lifting to planting was about the same for all forests, but the periods of local storage on the Sitgreaves and Lincoln National Forests were much longer. Of course, the sites also were different from the central Idaho sites. Because of the success of fall lifting and winter storage in Idaho, it seems advisable to make another test of the Sitgreaves and Lincoln National Forest ponderosa pine with more detailed monitoring of the conditions between shipping and planting. Survival and height growth will be measured for two more growing seasons.

Table 7.--*Comparative ranking*[1] *for each nursery seedling lot tested, based on first-year survival*

Time of lifting	Storage temperature	Package	Boise NF: Ponderosa pine, 1-0	Boise NF: Lodgepole pine	Boise NF: Douglas-fir	Boise NF: Engelmann spruce	Payette NF: Ponderosa pine, 2-0	Payette NF: Western larch	Sitgreaves NF: Ponderosa pine, 2-0	Lincoln NF: Ponderosa pine, 2-0	Bitterbrush
	°F										
Fall	28	Bag	G	G	A	G	G	G	NA	NA	NA
Fall	28	Crate	A	A	NA	A	NA	G	NA	([2])	NA
Fall	33	Bag	G	G	A	G	G	G	NA	NA	A
Fall	33	Crate	G	G	A	G	A	G	A	NA	NA
Spring	33	Bag	G	G	G	G	G	G	NA	A	G
Spring	33	Crate	G	G	G	G	G	G	NA	A	G

[1] Greater than 90 percent survival --- Good (G)
75-90 percent survival ------------- Acceptable (A)
Less than 75 percent survival ------ Not acceptable (NA)

[2] These seedlings were inadvertently removed from storage and mixed with nonstudy stock.

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USDA Forest Service
Research Note INT-196

July 1975

HYDROGEN PEROXIDE AND THIOUREA TREATMENT OF BITTERBRUSH SEED

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ABSTRACT

Bitterbrush seeds receiving a thiourea treatment or an array of hydrogen peroxide treatments were compared as to emergence rate and total emergence. Total emergence from some hydrogen peroxide treatments equaled emergence from the thiourea treatment. Peak emergence of thiourea-treated seed was greater in magnitude and 2 weeks earlier than the emergence peak of seed treated with hydrogen peroxide. Emergence patterns suggest that field use of hydrogen peroxide-treated seed may increase seedling survival through avoidance of frostkill.

OXFORD: 232.324; 18.525
KEYWORDS: seedling survival, germination (seed), *Purshia tridentata* DC., seed treatment, revegetation.

Thiourea has been the standard treatment for breaking seed dormancy in antelope bitterbrush (*Purshia tridentata* DC.) (Pearson 1957; USDA Forest Service 1974). Bitterbrush dormancy has also been overcome by stratification (Hormay 1943); by scarification by sandpaper or hot water, and stratification (Peterson 1953); by gibberellic acid and stratification (McConnell 1960); or by washing, scrubbing, and stratification (Carlson 1974). The thiourea treatment is preferred because it is simpler than the other treatments, and because it results in dry seeds that are easier to plant than moist, stratified seed. However, workers exposed to thiourea can suffer toxic effects (Sax 1968). Also, although thiourea is effective in overcoming physiological dormancy, field plantings of thiourea-treated seed are often unsuccessful.

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[1]The authors are, respectively, Range Conservationist and Soil Scientist, Intermountain Forest and Range Experiment Station, stationed at the University of Nevada, Reno.

In order to induce germination, Crocker (1916) suggested that hydrogen peroxide be used to increase the amount of oxygen available to embryos in dormant seeds. Pack (1921), Shearer and Tackle (1960), and Trappe (1961) used H_2O_2 to hasten and increase germination of forest tree seed. Riffle and Springfield (1968) increased germination of shrubs *Cowania mexicana* and *Cercocarpus montanus* by washing seeds with a 30 percent H_2O_2 solution. Stein (1965) field-planted conifer seed pretreated with 1 percent H_2O_2 solution and found emergence and survival increased in two of three tree species tested. In concentrations of 3 percent or less, H_2O_2 is not hazardous. The purpose of the study reported here was to test hydrogen peroxide as a safe and effective alternative to thiourea.

METHODS

Emergence of bitterbrush seed receiving a standard thiourea treatment was compared to that of seed standing or shaken in two concentrations of hydrogen peroxide. Seeds from California, Idaho, and Nevada were used to test the consistency of response among seed sources. Young seedlings were observed for abnormalities until they were outplanted.

Seeds treated with thiourea were soaked in a 3 percent solution for 20 minutes and then air-dried. A commercial grade 3 percent H_2O_2 solution was diluted to 1 and 0.5 percent for the seed treatments. Seeds were placed in a 1 percent solution and either allowed to stand for 3, 5, or 7 hours or mechanically shaken for 3 or 5 hours. Seeds in the 0.5 percent solution were subjected to the same treatments, with additional 16-hour stand treatment and 7-hour shake treatment. All H_2O_2-treated seeds were air-dried for 7 days except seeds in a duplicate 16-hour stand treatment that were planted wet. Untreated seeds from each seed source were also planted.

Each treatment was replicated twice for each seed source with 25 seeds per replicate. Seeds were planted in the greenhouse in January, in plastic flats (6 by 51 by 26 cm) filled with fine perlite. Depth of planting was 1 cm and spacing was 2 cm within rows and 2.5 cm between rows (treatments). Seed sources and all treatments were assigned at random to all flats subject to the constraint that no treatment was replicated for an accession within the same flat. Since location effect was judged to be extremely small, this departure from a completely randomized design was ignored in the statistical analysis.

Perlite flats were maintained near field capacity throughout the 12-week study period. Fungicide (Captan)[2] was applied equally to all flats as necessary.

Plant emergence was recorded every 7 days. A plant was considered to have emerged if its cotyledons were completely free from the surface of the perlite. Emergence results from each seed source were tested individually by analysis of variance for significant ($P<0.05$) differences between treatment means.

To prevent crowding within the flats, individual seedlings were removed and transplanted in separate containers as they emerged. Seedling appearance and root length were noted at this time.

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[2]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

RESULTS

Plant emergence was significantly different ($P<0.05$) among seed treatments within a seed source. Seed response to treatment was most often consistent among seed sources. Emergence in 37 of the 42 treatments tested was increased at least 10 percent over nontreated seed (table 1). Seedling emergence was greater from seeds treated with 1 percent H_2O_2 than 0.5 percent H_2O_2 for the 3-, 5-, and 7-hour soak treatment and for the 3- and 5-hour shake treatment. Mechanical shaking increased emergence over the standing treatment for the same time period in both 0.5 and 1 percent solutions.

Table 1.--*Total emergence of thiourea- and H_2O_2-treated seed. All treated seed were air-dried 7 days unless otherwise noted*

Treatment (hours)	Seed source		
	Nevada	California	Idaho
	-Percent-		
None	16	34	46
3% thiourea	74	90	72
0.5% H_2O_2			
Soak			
3	34	48	40
5	28	46	50
7	30	56	50
16	50	54	68
16[1/]	48	64	62
Shake			
3	49	50	40
5	48	44	64
7	52	50	60
1% H_2O_2			
Soak			
3	38	38	58
5	66	72	76
7	62	70	76
Shake			
3	50	86	92
5	78	82	82

[1/]Seed planted immediately without drying.

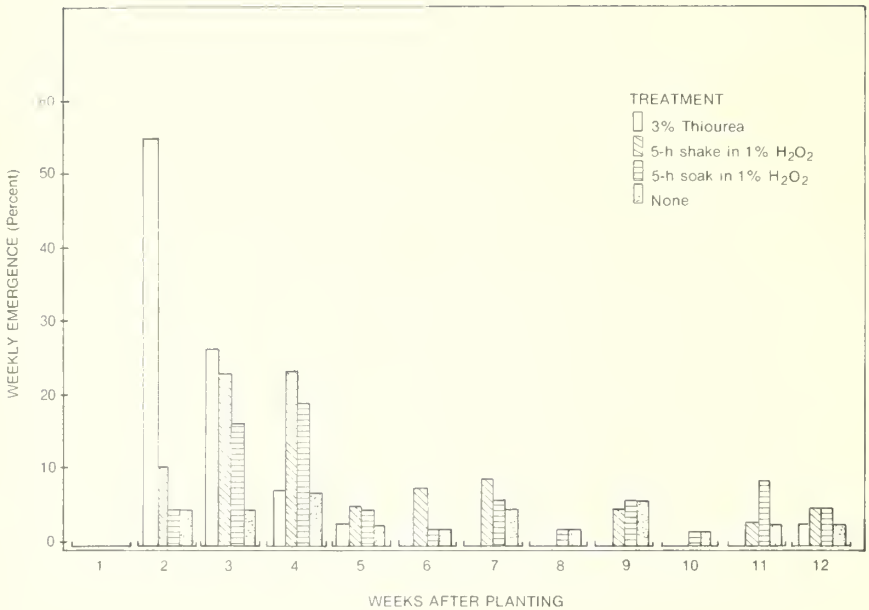

Figure 1.--Typical emergence pattern of antelope bitterbrush (Purshia tridentata *DC.*) *seedlings (California seed source).*

The magnitude and duration of emergence varied among treatments (fig. 1). Emergence of thiourea-treated seed was 90 percent completed by the second or third week. Emergence of H_2O_2-treated seed was more evenly distributed throughout the study period with a major peak in the third and fourth week. Peak emergence was always greater in thiourea-treated seed.

Seedling root length was similar at the time of emergence among treatments and there were no abnormalities noted in plant appearance. The seedlings continued to develop normally during the next 6 months before they were outplanted.

DISCUSSION

Throughout most of the range of antelope bitterbrush, and particularly in western Nevada, mild temperatures during early spring may be followed by hard frosts. This sequence kills seedlings (Ferguson and Monsen 1974) and the actively growing succulent tissues of mature plants (Smith and others 1965). Bitterbrush seedlings emerge during the mild period, and those in the cotyledon stage are easily killed by a subsequent cold snap. Plants that have developed to the first leaf stage are more resistant to frost and may not be severely affected.

The probability of complete seedling loss due to frostkill is less with H_2O_2-treated seed. The prolonged emergence pattern of H_2O_2-treated seed implies that only a portion of the seedlings are endangered by frostkill at any given time. The rapid emergence of thiourea-treated seed is excellent for dry sites, but a majority of the seedlings are subject to frost damage at the same time.

The choice of seed pretreatment for field planting should be based on the adaptation of the emergence pattern to the weather characteristics of the site. Where soil moisture is depleted rapidly and hard frost is not a problem, the thiourea treatment is more applicable. Where soil moisture gradually declines and hard frosts occur, the H_2O_2 treatment is more promising.

Field trials are underway to document emergence response to pretreatment under various soil and climatic conditions. Preliminary results indicate H_2O_2-treated seeds have greater emergence than thiourea-treated seeds when planted early but reduced emergence when planted in late spring. Further field evaluation is needed to define concisely those situations where H_2O_2 pretreatment is most effective.

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USDA Forest Service
Research Note INT-197

July 1975

ABANDONED MOUNTAIN PINE BEETLE GALLERIES IN LODGEPOLE PINE

Gene D. Amman, Principal Entomologist

ABSTRACT

During the fall of 1974, 129 galleries of the mountain pine beetle (Dendroctonus ponderosae *Hopkins*) *in 32 recently attacked lodgepole pines* (Pinus contorta *var.* latifolia *Engelmann*) *were examined to determine incidence of "pitching out." With one possible exception, galleries containing no females (33 percent) had been abandoned; females had not been pitched out. Small trees generally had a higher proportion of abandoned galleries, and these were usually longer than those in large trees. Low occurrence of males, which probably resulted in low incidence of fertilization in the attacking population on individual trees, is believed to be the factor responsible for gallery abandonment. Fertilized females constructed galleries and oviposited regardless of attack density.*

OXFORD: 453
KEYWORDS: insect damage, lodgepole pine, *Dendroctonus ponderosae* Hopk., bark beetle, gallery abandonment

Pitch tubes caused by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) attempting to infest lodgepole pine (*Pinus contorta* var. *latifolia* Engelmann) are common and can persist for years. Trees on which they are found are said to have "pitched out" beetles. Resin ducts are severed when the female starts construction of her egg gallery. If profuse enough, resin from these ducts forces the beetle from the gallery or the pitch kills her. Observations reported here indicate that in most cases females are not pitched out; instead, they apparently abandon galleries because they have not been fertilized.

METHODS

A total of 129 galleries on 32 newly infested trees were examined on three National Forests--Wasatch in northern Utah; Bridger-Teton in northwest Wyoming; and Targhee in southeast Idaho--in August 1974, 1 to 3 weeks after the beetle's flight period began. Trees were arbitrarily selected; therefore, data are not representative of the entire beetle population.

Galleries within a 6-inch-square area of bark were opened on each tree that received a full attack by the beetles. The lower 6 feet averaged two or more attacks per 6-inch area. These trees will die as a result of attacks. On lightly infested trees, all galleries were opened irrespective of bark area. Such trees had only one to five galleries on the lower 6 feet of the bole. These trees will not die as a result of attacks. The lower bole of lodgepole pine was examined because it is usually infested first by the mountain pine beetle (Rasmussen 1974).

Data recorded from each gallery were: (1) length of gallery; (2) female, present or absent; (3) male, present or absent; (4) eggs, present or absent; and (5) beetles entangled in the pitch tube or pitch in the gallery. When two beetles were in the same gallery, one was considered to be male; where no male was found but eggs were present, it was assumed the male left the gallery after fertilizing the female. This assumption seems reasonable because McCambridge (1970) observed that less than 2 percent of the new females are fertilized prior to emergence and attack.

In addition to the 1974 attacks, galleries from old attacks that occurred one or more years before were examined on 12 trees that were still alive.

RESULTS AND DISCUSSION

Results are largely from the Wasatch National Forest, where about 75 percent of the observations were made. In addition, these observations were made about 3 weeks after the flight period commenced; so little change would be expected in the number of attacking females being fertilized and laying eggs.

Examinations indicated that beetles were not "pitched out." Instead, apparently, 33 percent of the galleries were abandoned by females when they were not fertilized. An additional 10 percent of the galleries contained females, but no males nor eggs. These were potential cases for abandonment.

Pitch tubes at the entrances of galleries where females are actively boring are reddish because of frass in the pitch. After the female stops boring (apparently because fertilization has not occurred), she continues to keep the gallery free of pitch by pushing it out the entrance (see Blackman (1931) for an excellent description of this behavior). The pitch tube becomes cream colored when only pitch is pushed from the entrance. Further, it continues to increase in size as long as the unfertilized female keeps the entrance open.

Unfertilized females extended galleries to 2.2 inches; they abandoned the galleries if mating did not occur by then. Rasmussen (1974) reported that the unfertilized female makes about 2 inches of egg gallery in 8 days. Therefore, it would appear that a female will wait up to 9 days before abandoning the gallery. I found that abandoned galleries averaged 0.95 inch in length (N=42; SD=0.63); so, based on Rasmussen's (1974) observations of gallery construction by unfertilized females, the number of days before abandonment would average about four.

Lengths of abandoned galleries were usually longer in small diameter trees (fig. 1). Abandoned galleries averaged slightly more than 1 inch long in trees 9 inches d.b.h. and less, except the two 0.25-inch galleries in the tree 5 inches d.b.h. However, in trees 12 inches d.b.h. and larger, abandoned galleries averaged about 0.5 inch. In addition, the proportion of galleries abandoned was greater in small trees, ranging from 100 percent in the tree 5 inches d.b.h. to 20 percent in trees 12 inches d.b.h. (fig. 2).

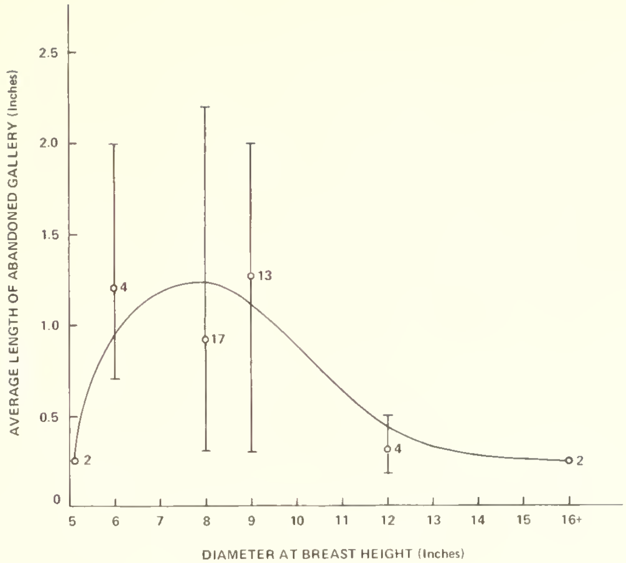

Figure 1.--Length of abandoned galleries for trees having different diameters at breast height. Data were taken from the Wasatch National Forest. Number by data point represents number of abandoned galleries examined. Vertical lines indicate ranges in observations; all galleries in 5- and 16-inch trees were 0.25 inch long.

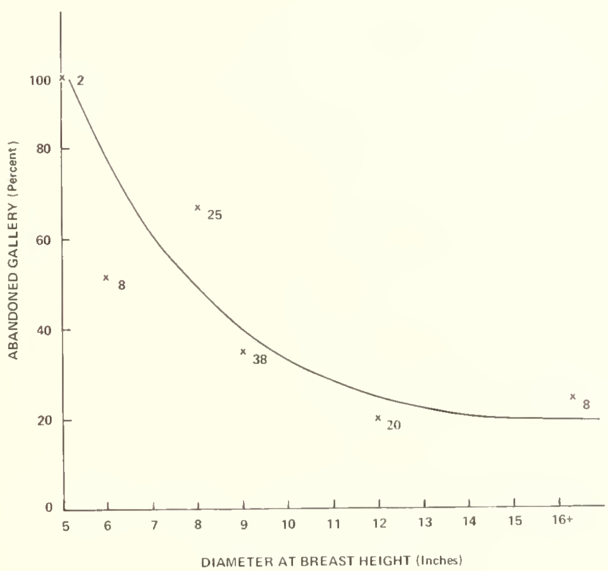

Figure 2. Percent of abandoned galleries for trees having different diameters at breast height. Data were taken from the Wasatch National Forest. Number by data point represents total number of galleries examined.

A possible explanation may lie in pheromone production. Most of the small trees were not fully attacked; so antiaggregative pheromone concentration (Rudinsky and others 1974) probably was low and unmated females might continue gallery construction while waiting for males. However, most large diameter trees were fully infested and concentration of antiaggregative pheromone could be expected to be high. Hence, females that were just starting egg galleries might leave in response to high antiaggregative pheromone concentration. Beetles that abandoned galleries probably flew to newly infested trees and constructed egg galleries in uninfested portions of the bark.

Pitch tubes and galleries, one to several years old, were examined in previously attacked, but living, trees. Galleries were up to 2 inches in length and resin filled. Areas in the bark over the galleries were necrotic. In some cases, phloem and xylem had almost grown over some old galleries. These galleries probably were constructed by unfertilized females also.

Only one dead female was found in a pitch tube resulting from 1974 attacks. No beetles died within the galleries indicating that "pitching out" as a result of tree response does not appear to be an accurate explanation for empty galleries. "Abandoned tree" would be a better term in most cases. Although true "pitching out" may occur, it appears to be much less common than previously thought.

Tree killing results when an adequate number of females and males are present in suitable ratio. I found that of the galleries examined on trees expected to die from the attack, 33 percent contained males and 78 percent contained eggs. In contrast, examinations of galleries in trees that would not be expected to die from the attack showed only 8 percent contained males and 43 percent contained eggs. The mountain pine beetle population in lodgepole pine almost always has a sex ratio that favors females. Reid (1958) found during a 3-year study that females constituted 67 to 70 percent of the population. The population that Rasmussen (1974) studied was 74 percent female. Sex ratios of attacking populations on individual trees could deviate considerably from these figures.

Unpublished data (Intermountain Forest and Range Experiment Station, Ogden, Utah) show that on the average small trees produce a greater proportion of females than large trees. Consequently, the shift of the attacking beetle population to smaller diameters toward the end of an infestation (Cole and Amman 1969) could increase the proportion of females in the population and the incidence of abandoned galleries. Both crowding (Cole 1973) and drying of bark (Amman and Rasmussen 1974) are involved in reduced male survival.

In the study reported here, the sample showed that most males abandoned the gallery soon after fertilizing the female. Males were found in only 16 percent of the galleries. Forty-one percent of the galleries had eggs but no males present. Galleries in which both males and eggs were present usually were longer ($N=10$); $\bar{X}=6.2$ inches; $SD=2.87$ inches) than those where eggs but no males were present ($N=46$; $\bar{X}=4.59$ inches; $SD=2.47$ inches). This difference may be related to the male's help in keeping the gallery free of boring frass by pushing it out of or into the base of the gallery (Reid 1958). Consequently, the female has more time for gallery boring and egg laying.

Of special significance is the fact that fertilized females constructed galleries regardless of attack densities--even when but one beetle attacked a tree. For example, a single female attacked a tree 7 inches d.b.h. and had constructed about 7 inches of gallery when the bark was examined. Eggs had been laid throughout the length of the gallery; however, heavy resin soaking occurred similar to that described by Reid and others (1967). In my study, this phenomenon was observed only in lightly attacked trees. Resin would prevent eggs from hatching, as was demonstrated experimentally by Reid and Gates (1970).

The fact that females continued to construct galleries and to lay eggs when only a few beetles attacked a tree strongly indicates that most successful attacks (those that result in gallery construction and oviposition) depend upon fertilization of the female. Success in terms of brood survival depends upon adequate attack and gallery densities that would prevent resin soaking of galleries and eggs.

Observations are needed to determine the extent of gallery abandonment and "pitching out" on a population basis. In addition, studies are needed to determine why males apparently respond more positively to some trees than to others under attack.

Production of the aggregative pheromone, *trans*-verbenol (Pitman and others 1968), may be one reason for positive response. Hughes (1973) reported that the presence of α-pinene initiated or increased biosynthesis of *trans*-verbenol by the beetle. Alpha-pinene was found to range between 2 and 50 percent of the terpene fraction of oleoresin in 11 lodgepole pines sampled in Montana (Lotan and Joye 1970); between 0.7 and 5.5 percent in five trees sampled in Canada (Shrimpton 1974); and between 5.0 and 7.4 percent in 10 trees sampled in California (Smith 1964). Other chemicals contained within the bark might also influence pheromone production (Vité and Pitman 1967).

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Research Note INT-198

July 1975

HABITAT TYPE AND SITE PREPARATION AFFECT SURVIVAL OF PLANTED DOUGLAS-FIR IN CENTRAL IDAHO BRUSHFIELDS

Jay A. Kittams and Russell A. Ryker[1]

ABSTRACT

*Survival and growth of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii *var.* glauca *(Beisn.) Franco) trees planted under shade on unprepared sites were compared with survival and growth of trees planted in adjacent 8- by 8-foot scalps. Survival and growth were also compared for auger- and bar-planting methods. The scalps increased third-year survival from 18 to 42 percent. Survival was higher for bar-planted trees on scalped plots, but on unscalped plots survival was higher for auger-planted trees. Trees on scalped plots grew 30 percent more than on unscalped plots. The effects of site preparation upon survival and growth appear to differ between habitat types.*

OXFORD: 232.2, 232.42, 182.3
KEYWORDS: Site preparation (artificial regeneration), seedling survival, *Pseudotsuga menziesii*, shrub competition, habitat types

Poor survival of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beisn.) Franco) plantings in shrub-covered openings has been a problem in central Idaho. Removal of shrub competition should increase the availability of soil moisture, but it also exposes the site. We have observed that protection of the site against environmental extremes is important for survival and growth of Douglas-fir seedlings on Douglas-fir habitat types.

If we prepare a planting spot by a large (8- by 8-foot) scalp, will the surrounding shrubs provide adequate protection against environmental extremes; or would the trees have a better chance without site preparation? This study was designed to answer this question.

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[1]The authors are, respectively, Forestry Technician and Silviculturist, stationed at Boise, Idaho.

When the study reported here was established in 1971, a habitat classification system had not been developed for central Idaho. A classification system was available (from preliminary forest habitat typing work by Pfister and others) before third-year measurements were taken; so we identified the habitat type of each plot during that measurement. The dominant habitat type is *Pseudotsuga menziesii/Physocarpus malvaceus (Psme/Phma)* with stringers of *Abies lasiocarpa/Acer glabrum (Abla/Acgl)* or *Pseudotsuga menziesii/Acer glabrum (Psme/Acgl)* in the swales, and *Pseudotsuga menziesii/Symphoricarpos oreophilus (Psme/Syor)* on slope crests.

Because the study was not designed to test differences between types, only limited statistical analyses were attempted. However, data summaries indicate strong correlations between habitat type and tree survival. Therefore, the results of seedling survival and growth are presented for habitat types, as well as for site treatments and planting methods.

The principal objective of the study was to compare survival and growth of Douglas-fir trees planted under shade on an unprepared site with survival and growth of trees planted in adjacent openings from which all aboveground vegetation had been removed. Survival and growth were also compared for auger- and bar-planting methods.

STUDY SITE

The study area is located within the Boise Basin Experimental Forest in the southwestern portion of the Idaho Batholith. Study plots are on 50 percent slopes in a north-facing basin at an elevation of 6,300 feet. Soils are sandy loams. Dense shrub vegetation covers the area, which was clearcut, but not burned, in 1968.

METHODS

Twenty blocks, each containing two 8- by 8-foot plots, were established the first week of June 1971. All blocks were on areas well covered by shrub vegetation ranging in height from approximately 2 to 6 feet. One plot of each block was randomly selected to receive no site preparation. All aboveground vegetation and litter on the adjacent plot was removed with hand tools.

Each plot had two rows with five trees each. The trees were planted 1 foot apart in rows approximately 2 feet apart. On site-prepared plots, this arrangement left a 2-foot buffer strip to plot edge. A 4-inch auger was used in planting one row within each plot; a planting bar was used in planting the other row. Planting stock was 3-0 Douglas-fir from the Lucky Peak Nursery, Boise National Forest. The trees were lifted March 25, 1971, and stored (34° F) at the nursery for 11 weeks, when snowmelt permitted planting. Trees were graded to uniform size at that time. The weather was cool and overcast when the trees were planted, June 9 and 10, 1971. The same two-man crew did all the planting.

Survival was recorded in mid-September of 1971, 1972, and 1973. Annual leader elongation on all surviving trees was measured to the nearest centimeter each time survival was recorded.

RESULTS

Survival

Third-year survival data show the 8- by 8-foot scalp increased survival from 18 to 42 percent (table 1). The increase was statistically significant at the 99 percent level. Though mean survival was higher (32 percent) for bar planting than auger planting (28 percent), the difference was not significant at the 95 percent level.

Table 1.--*Survival of planted Douglas-fir seedlings at the end of the third growing season*

Planting method	8- by 8-foot scalp	No scalp	Mean
	- - - - - - - -	*Percent* - - - - - - - -	
Auger	36	20	28
Bar	48	17	32
Mean	42	18	

A significant interaction occurred between planting method and site treatment. Survival was higher for bar-planted trees on scalped plots, but on unscalped plots survival was a little higher for auger-planted trees.

The effects of site preparation upon survival appear to differ between habitat types. Nine of our plots were located in the *Psme/Phma*, six in the *Psme/Acgl*, one in the *Psme/Syor*, and four in the *Abla/Acgl* habitat type. Effects were greatest on the *Abla/Acgl* habitat where Douglas-fir is a seral species (fig. 1). A *t* test for paired plots indicated a significant (95 percent level) increase in survival by site preparation on this habitat type, but not on the other three. In fact, no trees survived 3 years on the *Psme/Syor* plot.

Height Growth

Trees on scalped sites grew 30 percent more than those on unscalped sites during the 3-year study (fig. 2).

Weighted means show no overall difference between auger and bar planting (table 2). However, data from the table indicate an interaction between planting method and site preparation. There was 35 percent less growth of bar-planted trees on the unprepared sites. A similar interaction in the survival data was found to be significant by the analysis of variance. Too many plots with zero survival prevented an analysis of variance computation for the height growth data; but if we had been able to compute such an analysis, we feel it would have shown a significant interaction exists for the growth data also.

As with survival, the effects of site preparation on height growth appear to differ with habitat type (fig. 2). The (*Abla/Acgl*) habitat had the least growth response to site preparation even though this habitat had the best survival. Growth increase was nearly the same for *Psme/Acgl* (37 percent) and *Psme/Phma* (39 percent habitat types. However, a *t* test indicated that the growth increases associated with site preparation were not statistically significant at the 95 percent level.

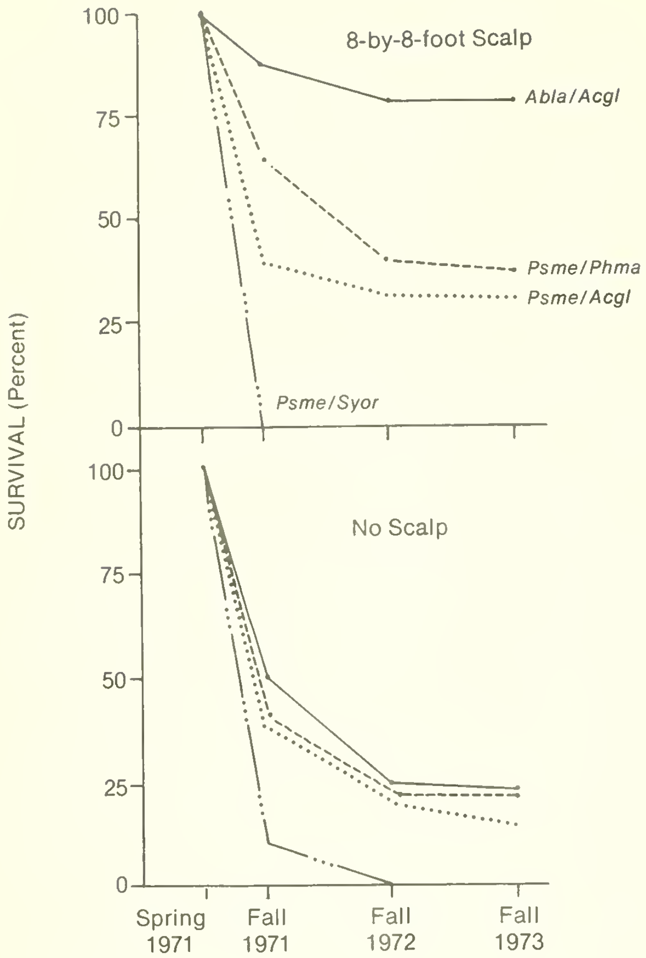

Figure 1.--Survival of planted Douglas-fir seedlings with and without site preparation on four habitat types: Abies lasiocarpa/Acer glabrum (Abla/Acgl); Pseudotsuga menziesii/Physocarpus malvaceus (Psme/Phma); Pseudotsuga menziesii/Acer glabrum (Psme/Acgl); Pseudotsuga menziesii/Symphoricarpos oreóphilus (Psme/Syor).

Table 2.--*Mean 3-year height growth of surviving trees*

Planting method	8- by 8-foot scalp	No scalp	Weighted mean
	- - - - - - - - - - - - *Centimeters*	- - - - - - - - - - - -	
Auger	6.2	6.0	6.1
Bar	6.7	3.9	6.0
Weighted mean	6.5	5.0	

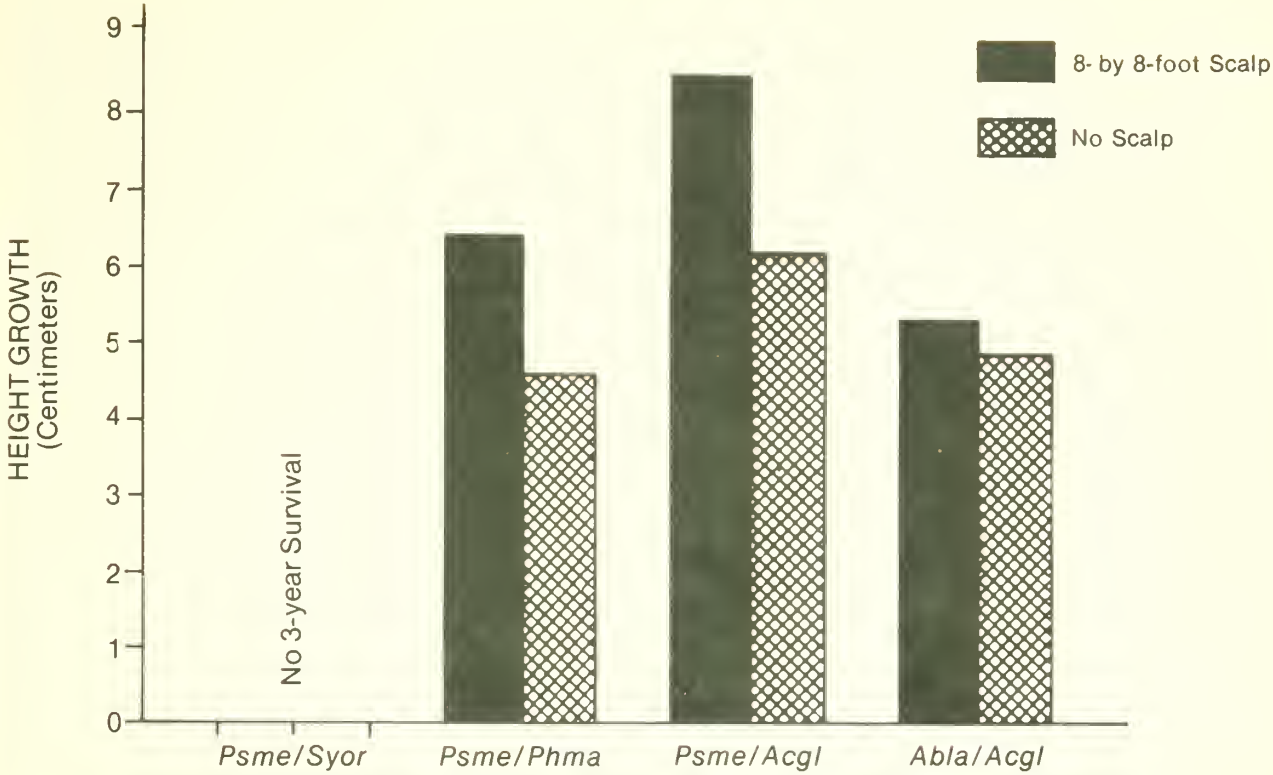

Figure 2.--Mean 3-year height growth by habitat type for trees surviving at the end of the third growing season. Habitat types are Pseudotsuga menziesii/Symphoricarpos oreophilus (Psme/Syor); Pseudotsuga menziesii/Physocarpus malvaceus (Psme/Phma); Pseudotsuga menziesii/Acer glabrum (Psme/Acgl); Abies lasiocarpa/Acer glabrum (Abla/Acgl).

DISCUSSION

As is generally accepted, site preparation increased survival and growth of planted Douglas-fir. However, the degree of response appeared to differ between habitat types.

The interaction between planting method and site preparation is difficult to explain. The poorer performance of bar-planted trees on undisturbed sites might be explained by difference in root competition. A well-planted tree in an auger hole has a world relatively free of competition in which to commence growth--for a short time at least. Bar-planted trees merely have their roots sandwiched between the root masses of competing plants. On prepared sites, competition is effectively removed. However, it is not clear why the bar-planted trees survived better than auger-planted trees on prepared sites.

Of the four habitat types represented in the study, *Abla/Acgl* is the coolest. It is moderately moist and supports a cover of tall shrubs. Douglas-fir is a productive seral species on this habitat type. Removal of competition appears to have increased survival, but the response in growth was quite small, perhaps due to the cooler temperatures. The *Psme/Phma* and *Psme/Acgl* are also moderately moist sites, but warmer than the *Abla/Acgl*. The greater growth responses to site preparation on the *Psme/Phma* and *Psme/Acgl* might be due to the warmer temperature. The *Psme/Syor* is a relatively dry habitat type occurring only on shallow soils in the study area. These sites appear to have been too severe for tree survival, and were not improved by site preparation.

Though we feel our treatment comparisons in this study are valid, we do not want to imply that the survival and growth obtained represent the best that can be expected on these sites. The quality of planting stock produced by the Lucky Peak Nursery has been improved since this study was made, and storage and handling procedures that better maintain tree quality have been adopted. These improvements coupled with selection of the best-adapted seed source should result in higher survival and greater growth on these habitat types than were obtained in this study.

RECOMMENDATIONS

This study reaffirms the need for prepared planting sites to insure success of plantations in Idaho brushfields; even on sites where natural Douglas-fir may become established under a shrub cover.

The degree of response to site preparation appears to vary with habitat type. We recommend that future studies be designed to clarify the effect of habitat types. Then future recommendations can specify the degree of site preparation needed and predict the growth and survival response by habitat type.

U.S. GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 5 REGION NO. 8

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USDA Forest Service
Research Note INT-199

August 1975

SOIL WATER DEPLETION BY LODGEPOLE PINE ON GLACIAL TILL

Robert S. Johnston[1]

ABSTRACT

*Soil water depletion was measured on small, paired plots of cut and uncut lodgepole pine (*Pinus contorta *Dougl.). Neutron measurements were made to a depth of 3 m on two different soils of glacial origin. Soils on the cut plot contained from 3 to 11 cm more water than the adjacent uncut plot at the end of each summer after cutting. These changes in soil water regimen were restricted to the surface 2 m of soil. The treatment effect should persist for several years, until deep-rooted vegetation is completely reestablished on the site.*

OXFORD: 114.12.
KEYWORDS: soil water relation; neutron moisture meter; clearcutting; water yield; *Pinus contorta* Dougl.; Uinta Mountains, Utah; glacial soils

The effect of management practices on water resources is a vital consideration in resource management. Water relation studies in many vegetation types clearly indicate that harvesting or other means of removing vegetation affects the soil water regimen of the site and can affect the amount and timing of water yields. It is important that land managers be able to assess these impacts for a wide variety of conditions.

Lodgepole pine (*Pinus contorta* Dougl.) is an important, widespread timber type in the western United States and Canada. The areal distribution of commercial lodgepole pine stands in Utah is 227,843 ha (563,000 acres), small compared to other western States, but third among Utah's timber types (Choate 1965). Its range is mostly restricted to the Uinta Mountains in the northeastern corner of the State, where average precipitation usually exceeds 76 cm (Hutchison and others 1965).

In Utah and many other areas, extensive stands are located on soils developed on glacial and on fluvial-glacial deposits.

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[1]The author is Research Hydrologist, stationed at the Forestry Sciences Laboratory in Logan, Utah, maintained in cooperation with Utah State University.

Several studies have explored the water relations of lodgepole pine growing on volcanic soils in Washington and Oregon (Bishop 1961; Herring 1968; and Dahms 1971), but little work has been reported on glacial tills. One deterrent has been the difficulty of soil moisture measurement in stony soils. The hydrologic effects of patch cutting lodgepole pine were studied in Colorado at about the same time this study was being conducted (Dietrich and Meiman 1974). That study was more intensive and of a greater scope than the study reported here. It included comparative soil-water measurements from small, paired clearcut and control plots at about 2,700-m m.s.l. on soils derived from gneiss-schist parent materials. A water balance was developed for each plot and the effect of cutting on the water yield of the site was estimated.

The scope of the study reported here is limited, but it provides an insight into soil water conditions under lodgepole pine growing in glacial tills.

AREA DESCRIPTION AND METHODS

The study area is on the north slope of the Uinta Mountains, south of Mountain View, Wyoming, at an elevation of about 3,040 m. Two sites, about 1.6 km apart, were selected in the upper Gilbert Creek drainage on contrasting, but representative, soil types. Both sites were essentially level, thus eliminating the effects of slope and aspect on water relations of the plots.

One site was on a broad ridge, where deep, stony, well-drained, sandy loam soil had developed on glacial till outwash (fig. 1). This soil overlays a thick deposit of stony, clayey, cobbly material of preglacial origin. The lodgepole stand was dense, with a basal area of 37 m^2/ha (160 ft^2/acre) and average tree height of 9 m. Average tree diameter was 11-cm d.b.h. with occasional trees measuring 25- to 28-cm d.b.h. Understory vegetation was sparse, making up about 1 to 2 percent of the ground cover, 75 to 80 percent of which was composed of litter (fig. 2). Roots were observed throughout the surface 2 m of soil and may extend to greater depths.

Figure 1.--The rocky soils of the ridge site are shown in this 4-m-deep road cut. The study site is about 30 m into the interior of the lodgepole stand.

Figure 2.--This view of the control plot at the ridge site illustrates the dense stand characteristics and near absence of understory vegetation.

The second site, adjacent to a large meadow, had deep, moderately-to-imperfectly drained clayey soil. Surface soil was silty clay loam with a heavy clay layer at about 1 m and a stony clay loam substratum. Occasional roots were observed below the clay layer. Trees were larger than at the ridge site; average height was 12 m and the mean d.b.h. was 25 cm with a basal area of 50 m^2/ha (216 ft^2/acre). Occasional trees measured 50 to 63-cm d.b.h. Understory vegetation, which comprised 8 to 10 percent of the ground cover, was denser than at the ridge, and had a greater variety of grasses and forbs. The litter layer was also thick at this site.

Two plots were located at each of the two study sites. Following a season of pretreatment measurements, one plot at each site was clearcut; logs were removed from the site and slash was piled and burned. Clearings were about 900 m^2 (0.22 acre). A trench, about 1.5 m deep, was dug around each clearcut plot to sever roots from the adjacent stand.

Four neutron access tubes about 3 m apart were installed to a minimum depth of 3 m near the center of each plot. Holes were drilled with a track-mounted rock drill coupled to a 9.9 m^3 (350 ft^3) air compressor. Soil water content was determined from measurements made with a Nuclear-Chicago neutron probe[2] beginning at a depth of 15 cm and continuing at intervals of 30 cm thereafter to the bottom of the hole. Measurements were taken shortly after snowmelt (June), in midsummer, and in mid-September of each of the three study years. Measurements were made 1 year prior to treatment and 2 years after cutting.

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[2]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

Some difficulty was encountered while installing access tubes in the dry, stony soils at the ridge site. Small stones and rock fragments were dislodged, jamming the drill bit. If excessive redrilling and blowing were required to free the drill steel, the hole was abandoned because of the possibility of creating voids and unduly disturbing sidewalls, which would cause measurement errors. The effects of rocks and voids on soil water measurements have been discussed by Koshi (1966) and Richardson and Burroughs (1972).

Drilling problems were not excessive, even under these difficult conditions. Some problems might be eliminated by drilling when soils are damp or by drilling inside a casing slightly larger than the drill bit. The casing could then be used in lieu of the normal access tubing or withdrawn after placement of access tubes. The extra large cavity would require careful backfilling. Either method would require testing and calibration.

Neutron probes need not be recalibrated for differing soil characteristics if data are used to compare differences in soil water content caused by treatment of adjacent plots. Calibration is essential if precise measurement of water content is desired. Pretreatment measurements, even those of short duration, provide valuable information as to inherent variability between plots and holes and disclose possible sources of error.

Precipitation was monitored at a climatic station located about midway (0.8 km) between sites. Snow depth and water equivalent was measured along a line transect through each plot to verify anticipated changes in snow accumulation patterns due to cutting. Snow measurements were made only once, during the peak accumulation period in April 1971.

RESULTS

Soil water depletion.--Soil water increased on both cut plots during each of the two summers following treatment. Average water depletion, the difference between June and September water content, is shown in figure 3.

Pretreatment measurements indicate an inherent difference of approximately 3.7 cm in average water depletion between the two ridge plots. The difference in seasonal water depletion between these plots increased to 14.8 and 12.3 cm during the 2 years after cutting. If pretreatemnt differences are considered constant, the water loss from the cut plot should be reduced to 11.1 and 8.6 cm, respectively, during the first and second summers after cutting. This change was confined to the surface 2 m, in which water content at the end of the summer was increased by 1 to 2 cm of water per 30 cm of soil depth. Little change in water content was noted below this depth.

There was little difference in water depletion between the two meadow plots prior to cutting. After treatment, water loss on the control plot was 3.1 to 3.5 cm greater than on the cut plot, considerably less than at the ridge site. All changes in water content on the meadow plots were confined to the surface meter of soil.

Table 1 lists average water content for all plots at the start and finish of the 3-year-study measurement periods. These data are based on factory calibration curves for the neutron probe and are subject to error when used in rocky soils. They are included to illustrate annual moisture variations and the range of water contents encountered in this study.

Figure 3.--A comparison of average water depletion (average of four holes to a depth of 3 m) for two glacial soils before and after clearcutting lodgepole pine.

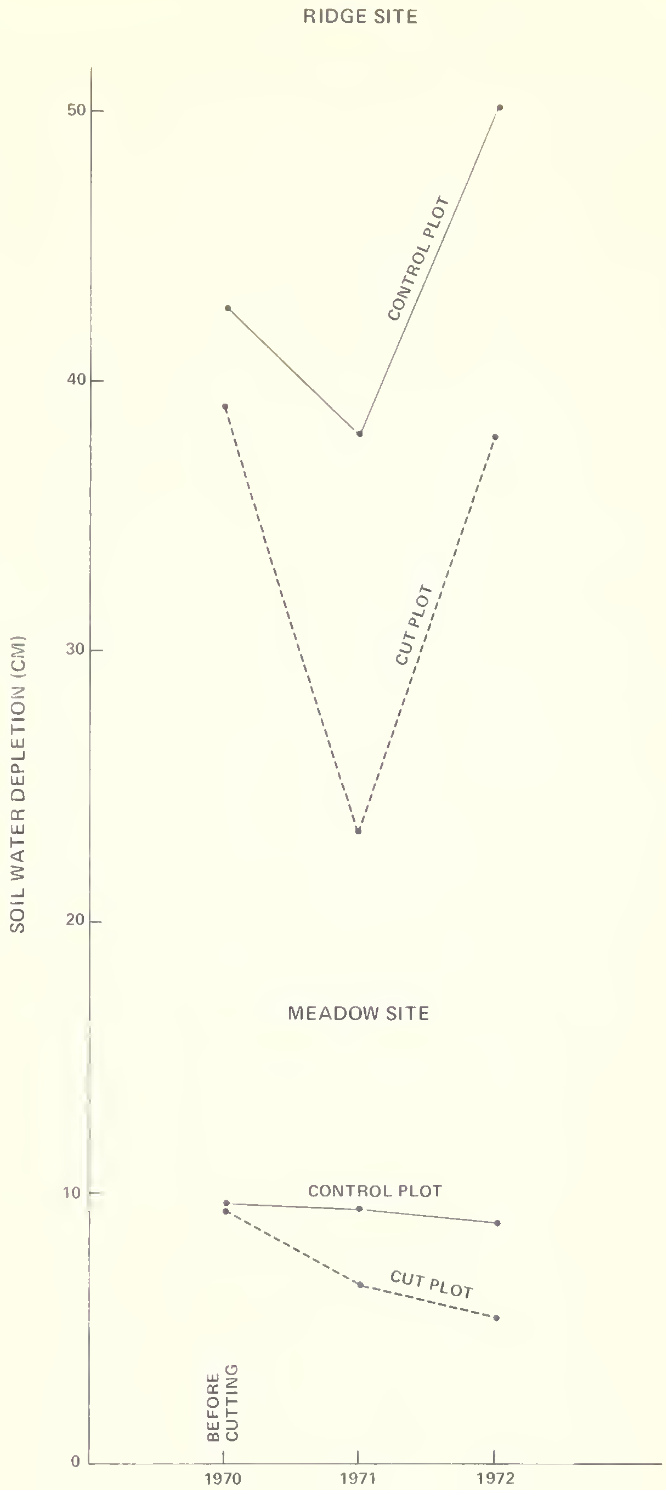

Table 1.--*Average soil water depletion*[1] *from cut and uncut lodgepole pine plots*

Item	1970 Uncut	1970 To be cut	1971 Uncut	1971 Cut	1972 Uncut	1972 Cut
	Centimeters					
RIDGE SITE						
Initial water content	85.9	75.4	80.2	71.0	87.1	79.2
Final water content	43.2	36.4	42.3	47.9	36.9	41.3
Depletion	42.7	39.0	37.9	23.1	50.2	37.9
Depletion difference	3.7		14.8		12.3	
MEADOW SITE						
Initial water content	93.8	91.1	92.5	91.3	90.4	89.6
Final water content	84.4	81.9	83.3	85.2	81.8	84.5
Depletion	9.4	9.2	9.2	6.1	8.6	5.1
Depletion difference	0.2		3.1		3.5	

[1] Average water content of four access holes to a depth of 3 m.

Greater statistical sensitivity could be achieved by increasing the number of sampling points per plot. However, the high cost of measurements and installing access holes usually prohibits intensive sampling in forest soils, which usually have a high inherent variability. Within-plot variance was greatest at the ridge site, where soils are stony and more heterogeneous than at the meadow. Using the variance indicated by the pretreatment measurements, we would need at least 12 sample points per plot at the meadow and 57 sample points per plot at the ridge to measure mean depletion within ±2.5 cm at the 95 percent confidence level.

Initial water contents for all holes varied slightly each year. At the ridge site, water content of the cut plot decreased until midsummer and then remained unchanged for the rest of the season. Water content of the control plot continued to decrease until the final measurement in mid-September. The effects of cutting at the meadow site were less dramatic. Water content decreased slightly throughout the season on both plots, but the rate of water loss was greater on the uncut plot.

Evapotranspiration.--Summer rainfall in the Intermountain West is generally light, seldom recharges more than the surface several centimeters of soil, and is rapidly lost because of high evapotranspiration. Therefore, rainfall between measurement dates is usually added to the measured water depletion to obtain an estimate of growing season evapotranspiration from the site. Summer rainfall varied at this study site from 18 cm in 1970 and 1971 to 13 cm in 1972. Addition of this rainfall to the water depletion of each plot increases the estimated total water loss from each plot, but does not alter the differences between plots attributed to the cutting treatment.

Snow accumulation.--Many studies have shown that small forest clearcuts influence the accumulation of snow. Interception of snow by tree canopies is eliminated and snow that is redistributed by wind action accumulates in small protected openings.

Snow depths and water equivalent were measured at both sites in April 1971. Average snow water equivalent was substantially higher in both clearcuts than in adjacent timbered sites.

At the ridge site, snow was deepest near the center of the cut plot and decreased toward both the east and west edges of the opening. The average water equivalent on the cut plot was 41 cm compared to 23 cm under the adjacent lodgepole stand. Maximum accumulation at the meadow site was along the downwind edge of the opening. Average water equivalent in the opening was 36 cm (slightly lower than at the ridge site), compared to 28 cm in the adjacent timber.

DISCUSSION

Soil water increased by as much as 11 cm in the surface 3 m of these glacial soils after cutting the lodgepole pine overstory. Treatment effects will gradually be reduced as the site once again becomes fully occupied by understory vegetation and trees. Natural invasion of vegetation on these sites appears to be slow; therefore, we might expect the treatment effects to persist for 10 to 20 years. Changes in water consumption following cutting lodgepole pine on these stony, glacially derived soils is less than that reported for volcanic soils in Washington and Oregon (Dahms 1971; Herring 1968). This fact may be attributed to differences in potential evapotranspiration, soil properties, and rooting characteristics.

Dietrich and Meiman (1974) reported an average increase in water content of 13.3 cm from small patch cuts in lodgepole pine in Colorado. Even though soils were different, the results compare quite favorably with soil water measurements reported in this paper for the drier site.

We did not anticipate the small differences in measurable soil water between plots on the meadow site. Differences in seasonal water withdrawal of only 3 cm between cut and uncut plots is not realistic and actual withdrawal by vegetation at the meadow site is probably much greater than indicated by this study. Water loss was not detected below the 1 m depth, the depth of the heavy clay layer, even though roots were observed at greater depths. Water loss at this site may be masked by continuous recharge from adjacent areas. If so, actual evapotranspiration would not be restricted by soil water deficit; so water loss should be higher than losses recorded at the drier ridge site.

Snow depth and water equivalent were substantially increased in the clearcuts, but melt rates are also higher in the open and snow disappeared at about the same date on all plots. There were no obvious changes in initial water content of the soils due to increased snow accumulation. Winter precipitation is usually adequate in this area to replenish soil water deficit on all but the most exposed, windy sites.

SUMMARY

This study has shown the feasibility of using mounted drilling equipment to install neutron access tubes in difficult stony soils. It has also provided a valuable measure of soil water relations to lodgepole pine growing on glacial tills. All moisture relations studies are site specific, but the study contributes to the ever-increasing evidence that timber harvesting can result in increased water yields.

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U.S. GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 7 REGION NO. 8

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USDA Forest Service
Research Note INT-200

August 1975

LOW COMPLIANCE RATES AT UNMANNED TRAIL REGISTERS

Robert C. Lucas[1]

ABSTRACT

Only 28 percent of the visitors to a portion of the Selway-Bitterroot Wilderness registered at voluntary trail registration stations. This is much lower than previous studies indicated and means some use estimates based on trail registers may be very unreliable.

OXFORD: 907.2, 905.9 (786)

KEYWORDS: recreation use estimation, trail registers, compliance rates, Wilderness, Selway-Bitterroot, Montana.

Unmanned, voluntary trail registers are commonly used in parks and forests in the United States and Canada primarily to provide information about visitor use for reports and management planning. Trail registers are the major alternative to mandatory travel permits for gathering use data (Hendee and Lucas 1973). About half of the National Forest areas in the National Wilderness Preservation System have trail registers rather than permit systems (Lime and Buchman 1974), and many other nonwilderness dispersed recreation areas have trail registers.

The problem with trail registers is obvious--not all people register. As a result, the information is incomplete, and use is understated. In addition, some types of visitors are more likely to register than others and, therefore, the information is also biased.

Two studies examined trail register compliance rates and concluded that a substantial majority of visitors registered. Wenger and Gregerson (1964) reported an overall registration rate of 74 percent for the Three Sisters and Mountain Lakes Wildernesses in Oregon in 1961 and 1962. Lucas and others (1971) estimated 65 percent of the visitor groups registered in the Mission Mountains Primitive Area in Montana in 1968.

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The similarity of the results of these two studies and the general similarity of the relationship of registration rates to factors such as method of travel, length of stay, local vs. nonlocal visitor origins, etc., suggested that registration rates might be reasonably consistent from area to area, and that data from trail registers provided a possible base for use estimates when adjusted for the minority of nonrespondents. This conclusion is now brought into question by new data, based on 1974 use of part of the Selway-Bitterroot Wilderness in Montana, that produced estimates of registration rates less than half the estimates of the previous studies.

STUDY AREA

The Stevensville Ranger District, Bitterroot National Forest, includes more than 100,000 acres of the Selway-Bitterroot Wilderness. This northeast corner of the Wilderness consists of the eastern slope of the main Bitterroot mountain range from Blodgett canyon north. About 10 major canyons, each with headwater lakes, are served by trails, and several other trails follow minor canyons or ridges to peaks or lakes.

Amount of use varies from moderate on some trails (more than 2,000 annual visitor days from trail register data) to very light on other trails (less than 100 visitor days). Most use is in the summer, predominantly day-use (from 45 to 88 percent of the groups registering at each trailhead take 1-day trips), and about 90 percent of the visitors are hikers.

Standard Forest Service trail registers (fig. 1), requesting each party to fill out and deposit a registration card, are located at all trailheads and have been in use for 4 years. All the registers are located at or very near the trailhead parking area.

Figure 1.--Standard Forest Service trail registers are used in the Selway-Bitterroot Wilderness.

STUDY METHODS

Five sample trailheads (table 1) were chosen in consultation with Ranger District personnel for a study of visitor impacts on trails and campsites. To better estimate actual use, trail registration compliance was studied on these trails.

Each trailhead was checked for a total of 7 days, once on each day of the week, during the first half of August 1974. Observers, not in uniform and not driving official vehicles (to avoid influencing visitor behavior), inconspicuously watched each trail register from about 8:00 a.m. to 5:00 p.m. daily. Visitor behavior was recorded on a tally sheet after the party had left. Party size, method of travel, and overnight or day use were all noted, as well as whether or not the party registered. Day users could be identified by the absence of backpacks or packhorses. None of the visitors were interviewed.

Table 1.--*Number of groups observed and percent registering at each of five Selway-Bitterroot Wilderness trailheads by selected group characteristics, 1974*

Type of user	Trailhead: Mill Creek	Bear Creek	Big Creek	Kootenai Creek	Sweeney Creek	Study area total
			DAY-USERS			
Observed	12	27	19	35	10	103
Registered (%)	25	22	16	17	20	19
			OVERNIGHTERS			
Observed	9	5	11	14	6	45
Registered (%)	33	20	82	36	67	49
			HIKERS			
Observed	16	28	27	44	14	129
Registered (%)	38	25	37	25	43	31
			HORSEMEN			
Observed	5	4	3	5	2	19
Registered (%)	0	0	67	0	0	11
Total						
Observed	21	32	30	49	16	148
Registered (%)	29	22	40	22	38	28

RESULTS

Only 28 percent of the 148 parties observed registered (table 1). (There is approximately a 95 percent probability that the range between 20 and 36 percent includes the true percent registering.[2]) This is well below half of the 75 percent estimate of the Oregon study (Wenger and Gregersen 1964) and the 65 percent estimate of the Mission Mountains study (Lucas and others 1971). On weekdays, the rate was slightly higher (30 percent) than on weekends (26 percent). This day-of-week difference agrees with the Mission Mountains study, but is the reverse of the Oregon study (Wenger and Gregersen 1964). The low rates were consistent from trail to trail (table 1); registration for all visitors at each trail varied from 22 to 40 percent.

Although registration patterns for various types of visitors in the Selway-Bitterroot were similar to those reported in the Oregon and Mission Mountains studies, registration rates for each visitor category were consistently much lower in the Selway-Bitterroot. In all the studies, overnight visitors were more likely to register than day users--49 percent compared to 19 percent in the Selway-Bitterroot Wilderness (table 1). Hikers complied better than horsemen--31 percent compared to only 11 percent in the Selway-Bitterroot. Only in the overnight visitor category were registration percentages even remotely similar between the Selway-Bitterroot study and the other two studies: Selway-Bitterroot, 49 percent; Oregon, 79 percent; Mission Mountains, 75 percent.

The relationship of party size to registration, not included in table 1, also followed the pattern of the Oregon and Mission Mountains studies. In the Selway-Bitterroot, only 10 percent of lone individuals registered, 35 percent of 2- to 5-person groups registered, and only 17 percent of the 6-person or larger groups complied.

DISCUSSION--WHY WERE REGISTRATION RATES SO LOW?

A number of possible explanations for the low registration rates in the Selway-Bitterroot Wilderness come to mind. First, use of the Selway-Bitterroot Wilderness might differ from use of the two other study areas. Not so--the types of use are very similar. The Mission Mountains and the two Oregon areas are predominantly summer, day-use, hiking areas without substantial outfitter use. Selway-Bitterroot registration was studied in the summer; the sample was 89 percent hiker, 70 percent day-use. Heavy use by horsemen, use by outfitters, and short stays--all associated with lower registration rates--do not explain the difference.

All three of the study areas draw most of their visitors from the local region, and the Oregon and Mission Mountains studies showed slightly lower registration by local people. The Selway-Bitterroot study area might draw a higher proportion of visitors from the immediate vicinity, but comparative data are lacking. However, residence was not a strong factor in explaining registration rates in previous studies. Furthermore, the Selway-Bitterroot study area and the Mission Mountains Primitive Area both draw many of their visitors from the same area. Possibly, a feeling by visitors that this section of the Selway-Bitterroot is "their backyard" has some effect, but it seems far too weak to explain the large difference.

People who had visited the area previously during the season had slightly lower registration rates in the Oregon and Mission Mountains studies. The Selway-Bitterroot has only slightly more repeat visitors than the Mission Mountains. Data on repeat

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[2]Interpolated from table 3, Confidence intervals for binomial distribution, 95 percent interval, p. 87, in *Elementary Forest Sampling*, Agric. Handb. 232.

visitors to the Oregon areas were unavailable. This factor also does not account for the striking difference. Design and location of station, sign wording, and registration cards were similar in all cases.

There were no wilderness management controversies, personalities, or other peculiarities apparent that would account for the very low rates.

Registration rates might be lower now than they were in the 1960's for reasons that are obscure but perhaps related to shifts in political and social attitudes. Wilderness use has been growing very rapidly and a great many visitors are new since the 1960's. Some of the new visitors may be indifferent to requests to fill out forms whose importance is not apparent.

The percentage of visitors that register at unmanned stations may vary much more than previously thought. Perhaps the high rate of registration in the two earlier studies was not typical. There are almost 90 National Forest Wildernesses, and sampling only 2 is inadequate. Electronic trail counters in the Idaho Primitive Area indicate only about 18 percent of the 1974 visitors registered.[3] An earlier study in Canada also reported very low rates--35 percent--for completion of a questionnaire at registers placed at attractions reached by trail (lakes, primarily) rather than at trailheads (Thorsell 1968). Thorsell attributed the low rate to the long, 19-question form, but it could be a warning of variability in registration rates. In contrast, Merriam and others (1973) report 95 percent of the parties observed in the Boundary Waters Canoe Area registered at special stations at campsites.

MANAGEMENT IMPLICATIONS

Managers using registration-based visitor data for management planning must be cautious. Applying an assumed registration rate or a formula developed elsewhere, or at an earlier date, such as that in the study of the Mission Mountains (Lucas and others 1971) could produce gross errors. On the other hand, using raw registration data without some correction might be extremely unreliable, also. Actual use in the Selway-Bitterroot study area is apparently three to four times what the raw registration data indicate. Furthermore, actual use is probably more than twice that previously thought, based on an assumed, typical registration rate. Reported use figures for units of the Wilderness System and general, dispersed recreation that were based on registration data might be just as unreliable. In many cases, reported use could be too low.

Registration rates in each area using trail registers should be spot-checked and periodically rechecked. Preliminary checking for 10 days or so at several well-used access points might indicate if rates are low and indicate the need for further checking to obtain more precise estimates. The difference between 65 and 75 percent registration rates in terms of use estimates based on each rate is about 15 percent. This is not good accuracy, but it is probably acceptable. But the difference in estimates based on 75 versus 30 percent registration rates is about 250 percent, which is clearly unacceptable. Furthermore, low registration rates provide an inherently unreliable base for use estimates (Lucas and others 1971, p. 37).

Efforts to raise registration rates might help. Education and publicity would be worth trying (Lime and Lorence 1974); many visitors may view registering as more akin to signing a guest book than an important contribution to the protection and management of the area. Stations *must* be serviced frequently--a station with no cards, pencil, or pen not only loses information, it feeds the visitor's doubts about the importance of

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[3]Personal communication from Earl F. Dodds, Ranger, Big Creek Ranger District, Payette National Forest, Idaho.

registration. Station design should be reevaluated. Brighter colors could be considered (the present brown and gray design blends in perhaps too well). Location very close to the trail's edge, perhaps even in conjunction with some kind of gate, real or symbolic, might improve visitor compliance. In at least one area, the present system is not working and some experimentation seems needed.

The relative advantage of permit systems over trail registers (Hendee and Lucas 1973) may be greater than thought. Permits may be the only reliable way to obtain important use data for increasingly demanding management planning (Lime and Buchman 1974). The trail register's usefulness is now in question. If trail registers are performing as poorly elsewhere as reported here and their performance cannot be improved, they need to be replaced with some different system.

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Research Note INT-201

September 1975

GENETIC VARIATION IN A PROVENANCE TEST OF 16-YEAR-OLD PONDEROSA PINE

G. E. Rehfeldt and R. G. Cox[1]

ABSTRACT

Trees at age 16 representing 13 provenances of ponderosa pine were compared in tests at two planting sites. Provenances represented a small portion of the species range in northern Idaho. Genetic variation among provenances was apparent for tree height, diameter at the ground, and number of branches in the upper two whorls. Trees that suffered the most damage from snow at the most severe site represented provenances characterized by the greatest growth rate.

OXFORD: 165.3, 232.311.21
KEYWORDS: plant genetics, seed-producing areas, snow damage, *Pinus ponderosa*

Racial variation characterizes the genetic system of ponderosa pine (*Pinus ponderosa*). Tests of provenances representing much of the species range show regional variation for numerous traits (Steinhoff 1970; Wells 1964; Squillace and Silen 1962; Hanover 1963; Wright and others 1969). The genetic variation that differentiates provenances within regions (Wright and others 1969) may be related to altitude of the provenance (Callaham and Liddicoet 1961).

In northern Idaho, ponderosa pine forms climax forests near the prairie-forest transition; it is a major seral component of the Douglas-fir (*Pseudotsuga menziesii*) series of habitats and the *Abies grandis-Pachistima myrsinites* habitat type (Daubenmire and Daubenmire 1968). Provenance tests that involved a small portion of the species

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[1]The authors are, respectively, research plant geneticist, Intermountain Forest and Range Experiment Station, stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho; and Manager, Environmental Forestry, Potlatch Corporation, Lewiston, Idaho.

range in northern Idaho were initiated by Potlatch Corporation to locate suitable sources of seeds for reforestation.[2] Because of the blister rust epidemic affecting western white pine (*Pinus monticola*), alternative pine species were desirable for reforestation. The objective of the tests reported here was to determine the existence of provenances capable of producing seed for trees adapted to the western redcedar (*Thuja plicata*) and hemlock (*Tsuga heterophylla*) series of habitats for which ponderosa pine generally is not suited.

MATERIALS AND METHODS

Two-year-old seedlings representing 13 provenances were planted in 1961 on two sites (fig. 1). Trees from nine provenances were planted on the Washington Creek site. This site is a *Thuja plicata-Pachistima myrsinites* habitat type at 1,220-m elevation; for each provenance, 100 trees were planted at a spacing of 2 m^2 in each of two square plots located at random throughout the planting.

The Crane Creek planting is an *Abies grandis-Pachistima myrsinites* habitat type at 880-m elevation and contained seedlings representing 11 provenances. Here only one provenance was represented in two plots. However, for each provenance 125 to 3,000 trees were planted at a spacing of about 2 by 3 m for each provenance in long row plots that extended the length of the relatively uniform site.

Hence, the Washington Creek plantation contained two replicates. The Crane Creek Plantation was not replicated except for one provenance.

After the trees were 16 years old, the following data were obtained for trees undamaged by snow, porcupines, insects, and cattle: 16- and 11-year heights, diameter at the ground, and number of branches in the upper two whorls. At Crane Creek, a systematic sample of 67 to 75 trees for each provenance was taken so that observations were available from entire plots. Because of high mortality and snow damage at the Washington Creek site, only 12 to 73 trees were measured for each provenance. Percentages of mortality and trees damaged by snow were estimated for each plot at Washington Creek. Snow damage included major bends in the stem, grotesquely deformed stems and branches, and broken tops. There was virtually no snow damage at Crane Creek, and mortality was minimal.

Although the Crane Creek plantation was essentially unreplicated, data from this planting are amenable to statistical analyses. Data from the one provenance that was established in two plots could be tested for experimental errors; a large number of trees were planted for each provenance; plots were established in long rows that traversed much of the environmental heterogeneity of the site; and, corroborative data were available from the Washington Creek planting.

Statistical analyses included an analysis of covariance of 16-year height on 11-year height and analyses of variance for all variables. Analyses were made to estimate effects of: (1) provenances at each site, (2) plots for the Brown's Creek provenance at the Crane Creek site, and (3) provenances, sites, and their interaction for the seven provenances common to both planting sites. Planting sites were considered fixed variates, and plots and provenances were random variates. Analyses of weighted means for unequal subclass numbers were made on the original data.

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[2] Use of trade or firm names is for reader information only, and does not constitute endorsement by the U. S. Department of Agriculture of any commercial product or service.

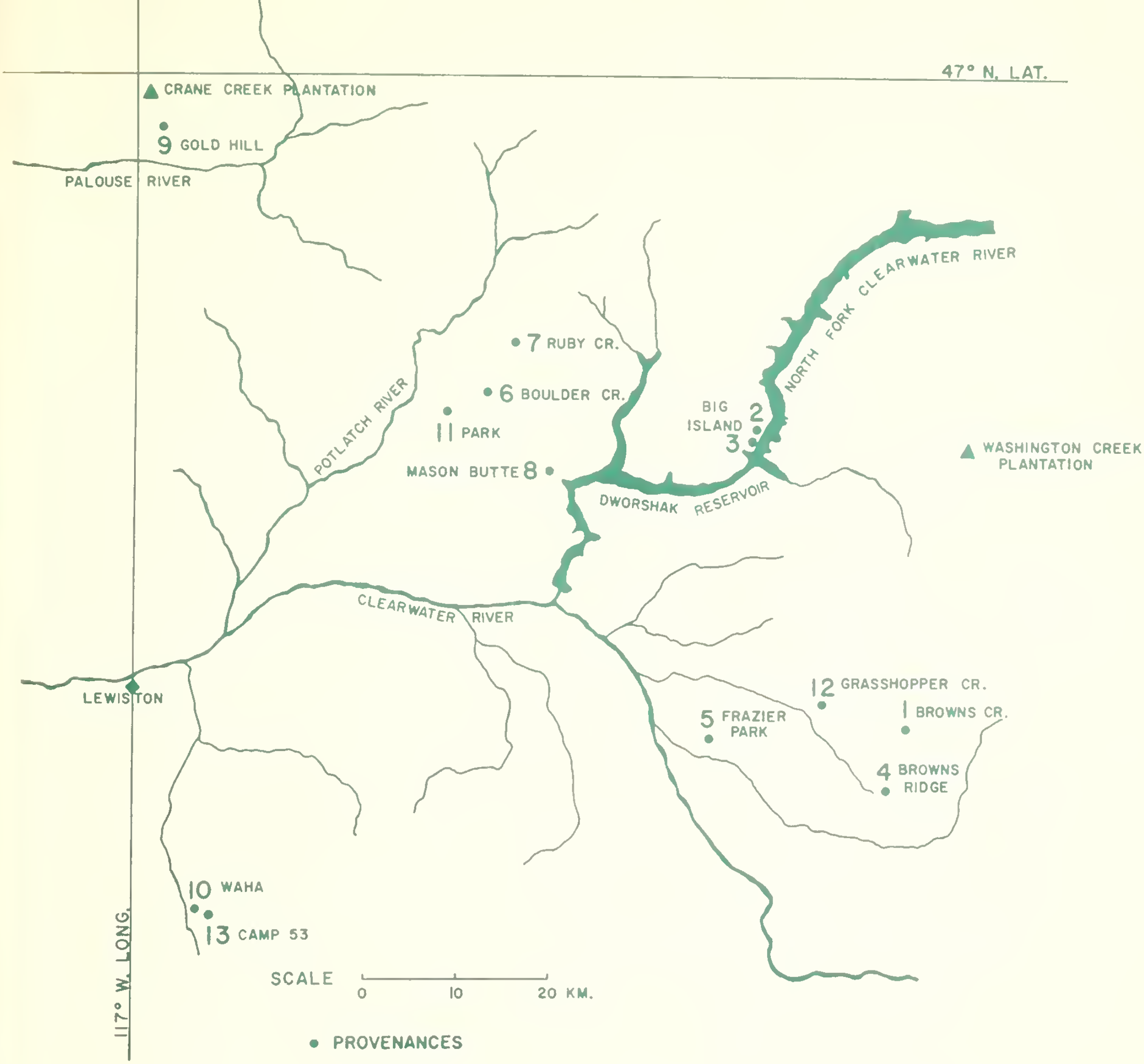

Figure 1.--Drainage map of a portion of northern Idaho showing location of provenances and plantations.

RESULTS AND DISCUSSION

Results of statistical analyses for the Crane Creek plantation (table 1) suggest genetic differences among provenances for all variables. However, the validity of these results is questionable. Effects of plots within provenances for data from Washington Creek were so large that it was impossible to detect significant effects of provenances. Effects of plots for the Brown's Creek provenance, the only replicated provenance at the Crane Creek site, were significant for three analyses. Mean differences associated with provenances at the Washington Creek site were of a magnitude similar to those at Crane Creek.

Table 1.--*Results of statistical analyses presented as intraclass correlations or the percentage of the total variance associated with each source of variance*

Source of variance	Degrees of freedom	Variables: 16-year height	11-year height	$d_{y.x}$[1]	Diameter at ground	Branches in upper two whorls
		CRANE CREEK PLANTATION				
Provenances	10	9**	10**	7**	8**	17**
Residual	794	91	90	93	92	83
		BROWN'S CREEK PROVENANCE AT CRANE CREEK				
Plots	1	12*	5	4	10*	15**
Residual	73	88	95	96	90	85
		WASHINGTON CREEK PLANTATION				
Provenances	8	0	6	13	0	0
Plots in Prov.	9	36**	31**	7*	32**	18**
Residual	347	64	63	80	68	82
		SITES COMBINED				
Sites	1	0	0	0	28**	0
Provenances	6	16**	17**	8**	5**	17**
Site × Prov.	6	6**	4**	1	4**	8**
Residual	784	78	79	91	63	75

[1]Deviation from regression of 16-year height on 11-year height.
*Significance of F value at the 95 percent level of probability.
**Significance of F value at the 99 percent level of probability.

Therefore, significant effects of provenances for the Crane Creek site seem inconsistent. However, consistent mean values for provenances at both sites (table 2) substantiate significant effects for provenances. Trees from the Big Island provenances were among the tallest at both plantings; those from Boulder and Ruby Creeks were the shortest. Diameters of trees from Brown's Ridge were among the largest at both plantings. Trees from Ruby Creek and Brown's Ridge produced the most branches; those from Frazier Park produced the fewest; and during the last 5 years, growth rates of trees from Frazier Park were far below the average at both sites.

Although diameters of trees growing at Washington Creek averaged 2 cm larger than those at the Crane Creek site, effects of planting sites were negligible for other variables (table 1). Most of the effects of planting sites were expressed by mortality and snow damage. Virtually no mortality nor snow damage occurred at the Crane Creek plantation. At Washington Creek, mortality averaged 53 percent, and 42 percent of the living trees were damaged by snow. Nevertheless, undamaged trees grew similarly on both sites. Except for snow damage, effects of interaction between provenances and sites are negligible. Effects were statistically significant, but intraclass correlations were low and were probably related to large inequalities in subclass numbers.

Table 2.--*Mean values representing each provenance at each planting site*

Provenance	Elevation	Trees in cone collection	Plantation: Crane Creek: 16-year height	11-year height	$d_{y.x}$[1]	Diameter	Branches	Washington Creek: 16-year height	11-year height	$d_{y.x}$[1]	Diameter	Branches	Mortality	Snow damage
	M	*Number*	*M*	*M*	*M*	*Cm*	*Number*	*M*	*M*	*M*	*Cm*	*Number*	*Percent*	*Percent*
1 Brown's Creek	1040	[2]--	5.0	2.4	0	12.4	9.3	5.4	2.6	0.18	15.5	9.3	50	47
2 Big Island-1	1060	[2]--	5.5	2.8	.10	13.2	9.8	5.5	2.9	-.02	15.5	8.8	45	67
3 Big Island-2	670	[2]--	5.1	2.6	.06	12.9	9.4	5.9	3.1	.09	16.0	8.7	62	92
4 Brown's Ridge	1220	12	5.5	2.7	.16	13.9	10.4	5.1	2.5	.04	15.5	9.3	45	30
5 Frazier Park	980	1	4.8	2.5	-.26	11.6	7.6	5.1	2.7	-.20	15.7	7.9	57	67
6 Boulder Creek	1070	12	4.7	2.3	0	12.9	10.1	4.5	2.1	.04	13.9	9.4	70	5
7 Ruby Creek	880	12	4.7	2.2	0	11.4	8.4	4.8	2.2	.14	14.2	9.4	45	7
8 Mason Butte	980	12	4.7	2.2	.15	11.9	9.2	--	--	--	--	--	--	--
9 Gold Hill	1160	5	5.0	2.6	-.10	12.4	9.2	--	--	--	--	--	--	--
10 Waha	1280	4	5.1	2.7	-.16	12.4	9.0	--	--	--	--	--	--	--
11 Park Community	920	[2]--	5.1	2.5	0	12.4	8.6	--	--	--	--	--	--	--
12 Grasshopper Creek	1040	[2]--	--	--	--	--	--	5.1	2.8	-.12	13.5	8.2	57	52
13 Camp 53	1280	3	--	--	--	--	--	4.9	2.5	-.22	13.7	8.6	50	9

[1]Mean deviation from regression of 16-year height on 11-year height.
[2]Cones were collected from an unknown number of trees.

The percentage of trees damaged by snow varied among provenances (table 2), and the amount of damage was related to mean height of undamaged trees. The provenance characterized by the tallest trees also had the largest percentage of trees damaged by snow. Conversely, the three provenances that had the lowest percentage of trees damaged by snow also had the smallest trees. This suggests that genetic variation among provenances in growth potential is inversely correlated with variation for strength to withstand large accumulations of snow. However, it is also possible that observed differences in snow damage actually reflect variation in growth rate and are confounded by differential mortality associated with provenances.

Snow damage in pole-sized ponderosa pine plantations often injures the tallest trees and is directly related to stand density (Powers and Oliver 1970). Yet damage from snow has been observed in ponderosa pines as small as 2 m (Oliver 1970); and little relationship between the percentage of trees damaged and mortality, a measure of stand density, was apparent (table 2). Therefore, growth rate and strength to withstand large accumulations of snow seem to represent different but correlated traits that genetically differentiate provenances. Similar results were obtained from 20-year-old provenance trials of ponderosa pine in California (Callaham and Liddicoet 1961).

Data from the Washington Creek plantation suggest that provenances of ponderosa pine are sufficiently heterogeneous to produce progenies preadapted to environments infrequently encountered by the species. Trees from each provenance produced offspring capable of withstanding the severe environment at Washington Creek; growth rates of preadapted trees were similar to those of trees growing at the Crane Creek site, which represents a common ponderosa pine habitat. That different percentages of preadapted trees characterized provenances attests to genetic variability.

Several tentative conclusions can be made from these results. Due to the superior growth rate but susceptibility to snow damage, seeds from the Big Island provenances are recommended for reforestation in areas where snow accumulations are light. Alternative sources of seed are available for areas in which heavy snow accumulations are expected. High growth rates accompanied by moderate amounts of snow damage can be expected from trees derived from Brown's Creek and Brown's Ridge. Maximum resistance to snow damage, but slow growth, can be expected from trees representative of Boulder and Ruby Creeks. Undamaged trees growing at the Washington Creek site represent materials suitable for development of races of ponderosa pine that are adapted to the western redcedar *(Thuja plicata)* series of habitat types.

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U S. GOVERNMENT PRINTING OFFICE: 1975 — 677-328 / 15 REGION NO. 8

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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USDA Forest Service
Research Note INT-202
1976

MASS SELECTION FOR BLISTER RUST RESISTANCE: A METHOD FOR NATURAL REGENERATION OF WESTERN WHITE PINE

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ABSTRACT

Seeds from surviving western white pine in stands that have sustained high (80 to 90 percent) mortality from blister rust produce 19.8 percent healthy seedlings--an 18 percent increase in resistance over that of the native population prior to introduction of blister rust. A breeding approach that would use this natural increase of resistance is proposed.

OXFORD: 172.8, 231, 165.38
KEYWORDS: *Pinus monticola*, white pine blister rust, natural regeneration, mass selection, resistance

White pine blister rust, caused by *Cronartium ribicola* J.C. Fisch. ex Rabenh., was first observed in the inland population of western white pine (*Pinus monticola* Dougl.) in 1927. Infection, which dated back to 1923 (Mielke 1943), spread slowly but steadily until 1940 when incidence increased rapidly. At present, rust occurs throughout the range of western white pine. Tree size and the amount of infection determine the swiftness and extent of mortality in the stand (Mielke 1943). Stands exhibiting low mortality are characteristically composed of overmature (150- to 200-year-old) white pine or are located where conditions are less favorable for blister rust infection. In the majority of the inland white pine populational zones, temperature and moisture conditions are near optimal for infection, and tree losses have been extensive.

As the infection level increases, a few trees remain free of disease or relatively so compared to adjacent trees. In 1950, the USDA Forest Service started a

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program to determine whether this phenotypic resistance is heritable. High amounts of resistance and a large number of resistance mechanisms have been found (Bingham and others 1971). Although, to date, we probably have detected only a few of the possible resistance mechanisms and underestimated the number of genes present (table 1) (there must be many, even 20-30 or more), we are rapidly incorporating this resistance into planting stock. Five seed orchards have been established and others are planned. The aim is to maximize the level of resistance and the number of resistance mechanisms as well as to maintain adaptability. Data pertinent to this program are presented in Steinhoff (1971), Bingham and others (1971; 1973), and Hoff and others (1973).

Since most man-guided breeding programs seem to yield populations that eventually lose much of their adaptability (National Research Council 1972), we can expect that the seed orchard approach could lead to populations deficient in adaptability. Loss of adaptability would be intolerable in the case of white pine, a long-rotation (80-year) crop, since the new population will be growing in a natural or seminatural situation under continual environmental stress from weather, insects, other diseases, and heavy competition from associated species.

Table 1.--*Observed resistance mechanisms in* Pinus monticola:Cronartium ribicola *system*

Mechanism of resistance	Hypothesized inheritance
Resistance in secondary needles to a yellow spot-forming race	Recessive gene
Resistance in secondary needles to a red spot-forming race	Dominant gene
Resistance in secondary needles to a yellow-green-island spot-forming race	Dominant gene ?
Resistance in secondary needles to a red-green-island spot-forming race	Dominant gene ?
Reduced frequency of secondary needle infections	Nondominant gene ?
Slow fungus growth in secondary needles	Polygene ?
Premature shedding infected secondary needles	Recessive gene
Fungicidal reaction in short shoot	Recessive gene
Fungicidal reaction in stem	Oligogene ?
Slow fungus growth in stem	Polygene ?
Tolerance to infection	?

The purpose of this paper is to discuss recurrent mass selection in natural stands, a breeding approach that could yield genetically diverse seed crops characterized by stable resistance and broad adaptability. The selection force would be the natural levels of blister rust inoculum. We think mass selection would yield the desired breadth of resistance and adaptability; infected white pines that remain in stands exhibiting high mortality appear to contain relatively high levels of resistance, and large numbers of parent trees are available to assure broad adaptability. Although natural processes would eventually solve the problem, they are often unsuitable and lengthy. We hope that judicious guidance of natural processes will accelerate development of a new population of resistant, broadly adapted white pine.

STABILITY OF RESISTANCE

The most frequent question asked about upcoming populations of rust-resistant western white pine produced naturally or by artificial breeding methods, is, "Will new races capable of neutralizing the resistance genes arise?"

Certainly races will arise; we have already seen at least two (McDonald and Hoff in press). It is necessary to assume that the rust is highly adaptable and will continue to evolve races for the breeder to contend with. Recombinations occur every year and can be disseminated by fruiting cankers, most of which are long lived. Then, too, pine infections are haploid; so each new recombinant, mutation, or both, can be immediately expressed.

So how can we stabilize the resistance in a new population? New races commonly arise soon after release of a new variety (van der Plank 1968; National Research Council 1972). The problems caused by breeding disease-resistant wheat, corn, potatoes, and other crops are well known. Tired of having their efforts neutralized time after time, the breeders developed a new breeding philosophy based on the coexistence of host and parasite. Diversity is the objective of most recent breeding schemes that should stabilize resistance in crop plants (van der Plank 1968; Watson 1970; Leppik 1970; National Research Council 1972; and others). This concept agrees with nature's method--diversity is the rule in natural ecosystems (Browning 1975). Accordingly, we believe that diversity, developed and maintained by a more natural breeding method, can best stabilize resistance to blister rust in western white pine.

Mass selection will provide a high degree of genetic diversity and resistance stability because the total array of resistance will be selected--not just those traits man can see; the total genetic diversity of the rust will be used as inoculum--not just the sample man picks; and all environments can be included in the selection--not just the few to be used in expensive artificial breeding programs.

Mass selection for blister rust resistance has been going on from 30 to 40 years--ever since blister rust killed the first white pine. Natural mortality in some white pine stands has reached 80 to 90 percent. Trees remaining in these stands have been mass selected for resistance to blister rust.

Resistance in White Pine Prior to Introduction of Blister Rust

Early workers recognized that western white pine was susceptible to blister rust (Spaulding 1929). In British Columbia, all but 9 of 500 trees planted in 1923 had been killed by rust by 1929 (Mielke 1943). A systematic sample of a square mile of heavily infected 40- to 50-year-old white pine disclosed that only 1 of 384 trees was free of living blister rust cankers (Bingham 1947). Bingham and others (1972) described a younger stand where only 1 of about 10,000 trees was completely free of living or dead cankers. In 1952, five seed lots were sown as controls in a test of blister rust resistance in progeny. The seed lots were collected from squirrel caches in five northern Idaho-northwestern Montana stands where rust mortality then ranged from almost none to about 15 percent. Control seedlings were artificially inoculated the fall of their second growing season and outplanted on three field plots where they have since received heavy natural inoculation. Annual examinations of individual trees were made from 1954 to 1958, and periodic examinations were conducted in 1966 and 1973. By 1973, 98 percent of the 371 control trees had been killed by the rust; 8 trees (2 percent) remained alive, but only 3 of these (0.8 percent) were free of living blister rust cankers. Hence, the original population of inland western white pine was highly susceptible to blister rust; only about 1 or 2 percent of the individuals in it were resistant under heavy rust exposure.

Resistance of Surviving White Pine

The pertinent question is, how much and what kind of resistance will the survivors in stands that have had high (80 to 90 percent) mortality transmit to their progeny? One answer is available in the control lots used in later (1964-66) tests of progeny chosen for resistance to blister rust. In these tests, control lots were from areas where mortality was high. These lots came from squirrel caches or from collections of wind-pollinated seed produced by infected trees.

Nearly 20 percent of the progeny from these control lots were healthy 2.5 to 4 years after inoculation (table 2). Compared to the recorded resistance level prior to severe selection by blister rust, this is an 18 percent increase. Seed lots from stands with little or no mortality were not included; so a good comparison was not possible. On the other hand, all data were derived from seedlings that had needle spots 9 months after inoculation, and we feel that the resistance indicated is conservative. Seedlings without needle spots were eliminated; this usually amounted to less than 2 percent.

Causes of the considerable year-to-year variation within seed collections are unknown. Possible explanations are variation in inoculation conditions, in racial composition of the inoculum, or in environmental influence on the expression of resistance. Nevertheless, the general level of resistance of all control collections is relatively high over the 3 test years.

The resistance shown in table 2 is made up of three resistance mechanisms:

1. *Premature shedding of infected needles.* Infected needles drop off before the fungus can enter the stem; therefore, seedlings with this trait remain healthy. This mechanism apparently is inherited as a single recessive gene (McDonald and Hoff 1970).

2. *Fungicidal reaction in the short shoot.* This reaction is initiated by the interaction of the fungus and tissues around the short shoot that results in the death of the fungus. This reaction is also thought to be inherited as a single recessive gene (Hoff and McDonald 1971; McDonald and Hoff 1971).

3. *Fungicidal reaction in the stem.* This reaction is the result of an interaction of the fungus and stem tissue that produces large patches of dead host tissue. Although the fungus is not killed, it is slowed or starved by the necrosis. This reaction is followed shortly by the formation of wound periderm, which can act as a barrier between healthy and infected host tissues. Inheritance of this reaction seems to be controlled by several genes (Struckmeyer and Riker 1951; Bingham and others 1960; Hoff and McDonald 1972).

Table 2.--*The level of resistance of seed lots collected from rust-infected western white pine stands with high mortality*

Control lot	1964 (4 yr after inoc.) Un-infected plants	Total plants	Un-infected plants	1965 (3 yr after inoc.) Un-infected plants	Total plants	Un-infected plants	1966 (2.5 yr after inoc.) Un-infected plants	Total plants	Un-infected plants
			Percent			*Percent*			*Percent*
DD[a]	12	85	14.1						
NN[a]	22	78	28.2						
OO[a]	10	88	11.4				4	40	10.0
SS[b]	17	69	24.6						
WW[b]	34	81	42.0	38	204	18.6	29	138	21.0
QQ[b]	11	37	29.7						
RR[a]	11	60	18.3	43	195	22.1	0	41	0
VV[b]	27	82	32.9				5	49	10.2
YY[b]	6	78	7.7						
XX[b]	14	61	23.0	13	121	10.7	36	145	24.8
TT[a]				23	150	15.3	29	133	21.8
ZZ[b]				28	65	43.1			
NR11 x Mix[c]				9	64	14.1			
NR12 x Mix[c]				1	10	10.0			
NR13 x Mix[c]				2	64	3.1			
NR14 x Mix[c]				3	17	17.6			
Total	164	719	22.8	160	890	18.0	103	546	19.0
Grand total	427	2,155	19.8						

[a]Collections from five wind-pollinated, rust-infected trees.
[b]Collections from squirrel caches.
[c]Crosses made on specific trees with a mix of pollen from 10 rust-infected trees.

Table 3 shows the frequencies of these three mechanisms of resistance. For comparative purposes, we have included data from the F_1 and F_2 crosses of resistant candidates and their progeny. Compared to the level of resistance in the original populations, considerable selection for these resistance mechanisms has taken place. Although we have partitioned resistance into three categories, two of which are presumably controlled by single genes, we have no data concerning the total number of resistance mechanisms nor of genes present in these surviving trees. An extensive study is underway that is expected to provide answers to these questions.

Table 5.--Percentage and gene frequencies of various mechanisms of resistance in western white pine to infection by C. ribicola

Seed lots	Recessive gene 1, premature needle shedding	g.f.	Recessive gene 2, fungicidal short shoot	g.f.	Bark reactions	Rust-free plants	Total seedlings
	- - - - -	- - - - -	- - - - -	*Percent*	- - - - -	- - - - -	
			1964 Progeny Test				
Susceptible[a]	5.6	0.24	[b] 3.0	0.12	[b] 14.6	22.8	719
F_1[c] (52 candidates X 4 testers)	7.9	.28	[b] 20.4	.45	[b] 24.1	39.3	16,046
			1966 Progeny Test				
Susceptible	14.5	0.38	[b] 2.4	0.15	[b] 2.9	18.9	546
F_1[d] (10 families)	19.9	.45	[b] 6.5	.25	[b] 10.2	32.7	2,876
F[e] (52 families)	47.4	.69	[b] 21.9	.47	[b] 16.8	65.8	3,061

[a] Wind-pollinated seed from infected parents in stands with high mortality.
[b] Values adjusted for previous mechanisms of resistance.
[c] Two parent crosses of individuals without cankers selected as phenotypically resistant candidates.
[d] Families from previous progeny tests that have shown uniformly high general resistance (Bingham and others 1960).
[e] Two parent crosses of resistant seedlings, derived from families in previous progeny tests, that have shown uniformly high general resistance.

THE NUMBERS GAME

Stands exhibiting high mortality still contain many living trees. Four stands that we have been investigating average 46 living trees per acre. According to Bingham and Rehfeldt (1970), trees 45 to 60 years of age will average 28 cones per year and 120 seeds per cone--3,360 seeds per year per individual tree. Haig and others (1941) reported that about 2 percent of the annual seed production will result in established seedlings (a living seedling 6 years after germination); therefore, each individual tree is expected to produce 67 seedlings per year. After disturbance due to fire or clearcutting, natural regeneration can occur successfully for 5 to 10 years (Haig and others 1941). Over a 5-year period one tree should produce 335 seedlings. If a stand that has shown high mortality averages 46 living trees per acre (table 4), 15,410 established seedlings can logically be expected. If 19.8 percent of these seedlings were resistant (table 2), each acre could end up with 3,051 healthy trees (table 5).

Table 4.--*Total living western white pines per acre in four high-mortality stands*

Stand	Tree total	Total living	Mortality
			Percent
Bertha Hill	390	70	82
White Rock Springs	190	48	79
Elk Creek	182	20	89
Pete's Creek	434	46	89
Average	299	46	88

Table 5.--*Potential numbers of resistant white pine seedlings that could be produced per acre through mass selection in stands with high mortality*

Cones per tree	28
Seeds per cone	120
Seeds per tree	3,360
Established seedlings (2 percent of seed in 6 years)	67
Years for natural regeneration, 5 to 10; choose 5 years	5
Established seedlings per tree	335
Average living trees per acre	46
Total established seedlings per acre	15,410
Percent resistance	19.8
Established resistant seedlings per acre	3,051

PRACTICAL USE OF MASS SELECTION FOR RESISTANCE TO BLISTER RUST

The beauty of using mass selection of naturally selected resistant western white pine is its simplicity. It can easily be incorporated into existing practices. Some foresters, exercising their biological intuition, have already used this approach. They believe that healthy, living white pines remaining after the rust has killed most of the trees in a stand must contain some resistance. We agree.

Our general recommendations for using mass selection are as follows:

1. Select contrasting sites that once supported good white pine stocking that has been reduced 80 to 90 percent by blister rust;

2. Remove dead or high-risk white pine (table 6) and other competing trees or shrubs;

3. Prepare a seedbed. The most economical practice would be to prepare the selected site during logging;

4. Remove seed trees from each site after adequate regeneration--at least 2,000 seedlings per acre.

The new population can be managed as a timber stand to produce fiber, as a seed production area to yield resistant white pine seed, or as both. After infection and mortality of the most susceptible seedlings, the level of resistance is expected to be 50 to 60 percent. This estimate is based upon data produced by our artificial breeding program (Bingham and others 1973; Hoff and others 1973).

If several seed production areas are established in the many contrasting environments throughout the inland range of western white pine, we would expect adaptability to be optimum because seedling selection will have taken place on natural sites by natural processes.

Table 6.--*Condition and rate of mortality of surviving western white pine trees in stands that have sustained various levels of blister rust mortality*

Condition	<10 percent			50 percent			>38 percent		
	Condition[b] of individuals in 1970	Trees dead by 1974	Condition of individuals in 1974	Condition of individuals in 1970	Trees dead by 1974	Condition of individuals in 1974	Condition of individuals in 1970	Trees dead by 1974	Condition of individuals in 1974
Excellent[a]	49	0	44	69	0	69	77	3	56
Good	1	0	4	17	1	3	30	4	19
Fair	0	0	2	10	2	9	16	5	18
Poor	0	0	0	3	2	6	8	3	12
Very poor	0	0	0	1	1	7	19	13	17
Dead (total)	0	0	0	0	6	6	0	28	28

[a] This is a visual rating class of the general appearance of the parent trees; blister rust cankers are ignored.

[b] First rating was completed in 1971, but, since cones were collected from all trees in 1970 and because changes are slight between years, we assumed the 1971 ratings would closely reflect conditions in 1970.

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USDA Forest Service
Research Note INT-203
1976

ESTHETIC EVALUATION OF TIMBER HARVESTING IN THE NORTHERN ROCKIES--A PROGRESS REPORT[1]

Dennis L. Schweitzer, James R. Ullrich, and Robert E. Benson[2]

ABSTRACT

Panels of judges have been evaluating the esthetic dimension of harvested areas in the Northern Rockies. Studies conducted in Wyoming and Montana agree with intuition in that forest scenes are generally liked less as the evidence of man's activities increases.

OXFORD: 615
KEYWORDS: harvesting (silvicultural) systems, esthetics, visual impact

The appearance of forest areas that have been harvested is an important determinant of the timber harvesting systems that will be used on the National Forests in the future. At the present time, esthetics are considered in planning timber harvesting through formal agency guidelines and through the judgment of landscape architects in laying out harvesting units. Our modest research effort is intended to supplement these procedures. This report is intended both to present our findings to date and to let the reader know the nature of our work.

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[1]Most of this work has been carried out under a cooperative agreement between the University of Montana and the Intermountain Forest and Range Experiment Station. We acknowledge the contributions of Maureen F. Ullrich and Roy F. Touzeau of the University of Montana in collecting data and developing the methodology reported here.

[2]The authors are, respectively, principal economist, Intermountain Station; Associate Professor, Psychology Department, University of Montana; and research forester, Intermountain Station. Schweitzer and Benson are stationed in Missoula, Montana, at the Forestry Sciences Laboratory, maintained in cooperation with the University of Montana.

Numerous questions need to be answered before our efforts will yield answers that can be consistently used in complex decisions involving timber harvesting practices. These questions include:

1. Do individuals and groups with differing backgrounds differ widely in their perceptions of, and judgments about, the visual appeal of harvested areas? If so, how do they differ?

2. Do judgments of visual appeal depend upon the physical perspective or vantage point of the viewer?

3. Can judgments of case study areas be usefully quantified, are they reliable, and can they be generalized for application elsewhere?

In cooperation with researchers of the Rocky Mountain Forest and Range Experiment Station at Tucson and the University of Arizona, we are attempting to answer these questions. For the immediate future, our major efforts will lie essentially in adapting already-developed methodologies to the particular need of evaluating alternative harvesting systems in the rugged topography of western Montana.

An individual's visual perception of a harvested area depends in part upon his physical position relative to that area. We have divided our research efforts into determining

1. The impressions received when near or within a stand which has recently been harvested (that is, "near-view"), and

2. the impressions received when a stand is viewed from a distance, as from across a valley ("far view").

To date we have concentrated on obtaining quantitative and reproducible evaluations of the first, the near-view perspective, because a well-tested technique has been available (Daniel and Boster, in press). We are beginning preliminary work to validate the use of this technique or some substitute for evaluating far views; this may well be more significant in the Northern Rockies in light of the rugged topography.

TECHNIQUE USED

To date we have relied on the Scenic Beauty Estimation method (SBE) to define preferences for harvested areas; the mechanics of this technique, its validation and a wide range of applications have been thoroughly described by Daniel and Boster (in press). Essentially, the technique amounts to taking color slides or photographs of areas of interest and having groups of judges report on their degree of like/dislike for each. The process can be broken down into the following steps:

1. *Selecting areas to be evaluated.*--In the next section we report on evaluations of newly logged areas on the Teton National Forest in Wyoming and on the Bitterroot National Forest and Coram Experimental Forest (Flathead National Forest), both in Montana.

2. *Representing the areas as photographic slides.*--Because it is impractical to transport many viewers to sites that require evaluation, we have chosen to represent those sites through photographic slides. In our work, slides have been selected to represent the views that would be seen by an observer walking near or through the treated areas. Esthetic judgments seem to be unaffected by a rather wide variation in photographic quality, perhaps because of the radical differences between clearcut, partially cut, and uncut stands that we have compared. Presumably, photoquality would be more critical if we were attempting to measure more subtle differences, but this point has not yet been validated.

3. *Selecting panels of judges to evaluate the slides.*--Typically, evaluations are collected from a group of 25 or more judges at one time. Most of our work has been done with volunteer undergraduate students attending the University of Montana. Ullrich and others (1975) found that for a single set of slides of harvested and unharvested old-growth stands in Wyoming and Montana, essentially identical preferences were assigned by:

--psychology undergraduates at the University of Montana,

--psychology undergraduates at the University of Michigan at Flint,

--Montana elementary school teachers, and

--Montana Forest Service researchers.

Daniel and Boster (in press) conducted extensive studies with a wide variety of interested groups and found that, while numeric ratings vary somewhat by groups, average group evaluations ranked different landscapes in a consistent manner.

4. *Collecting judgments from the panels.*--The judges have been shown series of slides and asked to rate their preferences on a categorical scale from 0 to 9. There are a number of slides of each of several treatment areas. From all the photographic replications for a given area, one slide from each area is randomly selected to form a block; the order of presentation of the slides within each block is also randomized. Each block then consists of one picture of each area. Blocks are then shown until all of the photographic replications are used. This procedure usually requires a total of about 100 slides and 20 minutes of time.

5. *Reducing judgments to averages for selected areas on the ground.*--The judgments provide a set of numbers reflecting the panel members' perceptions of esthetic attractiveness. Daniel and Boster (in press) have pointed out that working with raw scores alone can be misleading if different panels use the 0-to-9 rating scale in different ways, especially if some tend to use the upper end and others the lower end of the scale. The authors have developed a method of mathematically transforming raw scores to avoid this problem. In addition, their transformed numbers meet all theoretical requirements for calculating means and variances and applying standard statistical tests of differences. Because, in our work to date, the results of working with such transformations are no different than the results obtained directly from the raw scores, no transformations are included in the present paper. (The transformed scores are available upon request.)

6. *Confirming that the average evaluations of treated areas from most- to least-preferred would be the same if made on the ground.*--To date we have not independently confirmed that this is true. Research carried out in the southwest and reported by Daniel and Boster (in press) strongly suggest the same esthetic judgments would be made based on slides as would be made by the same observers in the forest.

We have applied this general technique in the three areas described in the next section. For convenience of presentation and ease in reading, we have adopted the convention that all raw data scores are presented as if judges had used a 0-to-9 categorical scale from "dislike" to "like." In fact, in some instances the judges were instructed that 0 represented "like" and 9 represented "dislike." (The literature of psychological testing suggests judges would be only slightly influenced by scale reversals in ranking treatments.) We have used this convention in our most recent work and intend to use it in the future.

EMPIRICAL FINDINGS THROUGH JUNE 1975

We have evaluated logging practices in three different areas:[3]

Area	*Principal Comparison*
Teton National Forest northwestern Wyoming	Alternative treatments of logging residues in old-growth lodgepole pine
Bitterroot National Forest western, Montana	Logging by horses, crawler-tractor skidders and wheeled skidders in old-growth lodgepole pine
Coram Experimental Forest (Flathead National Forest), northwestern Montana	Clearcutting and shelterwood cutting in old-growth fir-larch

TETON STUDY

In 1971, a study was begun to evaluate a system of harvesting mature lodgepole pine in which virtually all the logging residue--branches, tops, and dead and cull material--was yarded and chipped at the logging site (reported in detail in Benson 1974). The study area is located in Wyoming near the Union Pass area of the Teton National Forest.

Four units of approximately 20 acres each were harvested by clearcutting. Two of the units were logged following conventional practices for that part of Wyoming. Saw logs to a 6-inch top were removed; the remaining material was left for burning on the site. The other two units had "near-complete" removal of slash; in addition to taking out the merchantable saw logs, virtually all the remaining material was yarded and chipped. On the near-complete units, a feller-buncher and rubber-tired grapple skidder were used in connection with an in-the-woods chipper.

Esthetic evaluations of six different logging and residue treatments were made by a panel of students. They rated a series of slides taken to represent the views of an observer hiking or driving alongside the treated areas on a 0-to-9 scale; summary statistics are presented in table 1. The median ratings show that half the judges rated the treatment higher and half lower than the value shown.

From these data, the judges most preferred scenes of unharvested areas and least preferred scenes of a recent clearcut where logging residues had recently been piled and burned. Clearcut areas where vegetative regrowth had started to mask the partially burned residues or where the residues had been converted to chips that were then spread throughout the harvested area were judged intermediate in esthetic value. The panel's judgments agreed closely with independent evaluations made of the area by a Forest Service landscape architect.

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[3]Detailed physical descriptions of all study areas have been reported in the internal report, "Forest residues utilization research and development program: progress report I," March 1975, 126 p. USDA For. Serv., Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1.--*Evaluations of harvested and unharvested old-growth lodgepole pine stands on the Teton National Forest*

Treatment	Median rating
Edge between meadow and unharvested old-growth stand	8.00
Unharvested old-growth stand	5.85
5 years after clearcutting with residues piled and burned	4.25
1 year after clearcutting with chips spread over area	3.90
1 year after clearcutting with near-complete removal of residues	3.65
1 year after clearcutting with residues piled and burned	2.15

BITTERROOT STUDY

In 1974, a number of small units averaging about 1-1/2 acres were clearcut in small-diameter, old-growth lodgepole pine on the Bitterroot National Forest to determine the productivity of several logging systems including rubber-tired skidding, crawler-tractor skidding, horse skidding, and a combination of horse and rubber-tired skidding. Photographs were taken before and after harvesting to determine whether near-view esthetic values varied by the skidding method used.

Because of the small size of the clearcut areas, the photographic slides were taken from the periphery of each cutting unit, oriented inward. These slides were then evaluated by 29 students (summary results are presented in table 2).

Higher scores indicate those skidding methods that were relatively liked. Although the uncut stands were all preferred to any of the stands after harvest, no statistically significant differences (regardless of the level of probability) were found among the areas either before or after harvesting.

It is important to recognize the dangers of trying to extrapolate the results from this small experiment to generalizations about the esthetic dimension of the examined skidding systems. For example, the woody material left on the ground after logging averaged nearly 1,000 cubic feet per acre, quantities which might well have led to different esthetic evaluations than if only a few pieces had remained. Further,

Table 2.--*Evaluations of four different skidding methods used in the Bitterroot National Forest*

Skidding method	Mean rating	
	Before harvest	After harvest
Combination horse and rubber-tired skidder	3.82	1.60
Crawler-tractor skidder	3.69	1.98
Rubber-tired skidder	3.53	1.91
Horse skidder	3.43	1.67

the evaluations probably were influenced by the small size of the clearcut areas, which averaged about 1-1/2 acres each, and by every photograph having a background of uncut forest. We can only state with assurance that our particular study did not detect differences among the appearances of the small areas that were harvested.

CORAM STUDY

In 1974, old-growth stands in the Douglas-fir and western larch forest type in northwestern Montana were harvested under several different silvicultural prescriptions to test the ecologic, economic, and esthetic consequences. Two stands each were harvested by clearcutting, group selection cutting, and shelterwood cutting techniques. Each stand was divided further into subtreatments by the manner in which the logging residues and understory were to be treated before, during, and after harvesting.

PREHARVEST AND POSTHARVEST EVALUATIONS

To determine the extent of preharvest differences in the stands, a series of near-view pictures were taken in June 1974 of areas to be shelterwood-cut and clearcut. (The group selection areas were omitted.)

In the subtreatments designated as "weed and bundle" areas (where trees to a 1-inch diameter were removed), all 5-inch and smaller trees had been cut and tied in bundles which were lying on the ground (and which were later removed from those areas during overstory harvest). Generally, these areas contained small, freshly cut stumps as well as the ends of the bundled trees; in addition, the forest canopies were more open than in the other subtreatments.

Two physical constraints dictated the method of obtaining the photographic slides. Because the subtreatments consisted of long, narrow areas on the ground, all photographs were oriented along the long axis to avoid confounding judgments with backgrounds of different areas. Because we had little idea of how the steep topography would influence esthetic judgments, half of the photographs were oriented uphill and half downhill.

The photographs were shown to a panel of 29 students. The mean scores are presented in table 3. Based on Tukey's HSD test (Winer 1971), when evaluations were appropriately pooled the following differences were found to be statistically significant at the 0.05 probability level:

--the to-be-clearcut unit was preferred to either of the future shelterwood units;

--the areas with undisturbed understories were preferred to those containing bundles of small trees; and

--photographs looking uphill were preferred to those looking downhill.

A general analysis of variance (assuming fixed effects) revealed significant interaction between treatments and photographic replications, that is, there were some slides from generally liked areas that were disliked and there were slides from generally disliked areas that were liked. We hypothesized that if a particular slide happened to present an unattractive object in the foreground of a generally liked area that slide would be relatively disliked. Because we want to establish overall ratings of like-dislike for each of the treatment conditions, we have ignored the statistically significant interaction among individual slides.

Table 3.--*Preharvest esthetic evaluation of Coram areas destined to be shelterwood-cut and clearcut*

Harvest method	Understory[2]	Camera orientation	Mean[1] rating
Shelterwood	Undisturbed (11-4)	Uphill	6.22
		Downhill	5.49
	Weed-and-bundle (11-3)	Uphill	5.27
		Downhill	5.39
Shelterwood	Undisturbed (21-4)	Uphill	6.20
		Downhill	5.60
	Weed-and-bundle (21-3)	Uphill	6.01
		Downhill	4.38
Clearcut	Undisturbed (23-4)	Uphill	7.22
		Downhill	6.41
	Weed-and-bundle (23-3)	Uphill	6.56
		Downhill	6.32

[1]A difference of 0.72 between any two numbers in this table is statistically significant at the 0.05 level. Smaller differences between pooled judgments, as reported in the text, are significant.

[2]Numbers in parentheses are treatment and subtreatment designations.

After harvest was completed in the fall of 1974, photographs were taken of clearcut and shelterwood cut areas (a mixup led to not completely replicating the pretreatment areas). A group of 32 students[4] then evaluated a mixed group of precut and postcut slides; the results are presented in table 4. Using the same statistical testing procedures as before, we concluded that:

--both shelterwood areas before harvest were preferred to either the shelterwood or clearcut area after harvest; and

--the harvested shelterwood area was preferred to the harvested clearcut area.

Although uphill photographs were again favored over downhill photographs, the difference is not statistically significant (the understory in three subareas had been slashed when postharvest photographs were taken; the understory in one other subarea had been inadvertently torn up during harvesting).

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[4]The judgments of two student panels, of 18 and 14 members, were pooled because no statistically significant differences could be found between the group scores, and the experimental conditions were judged by the experimenters to be similar. The data underlying (preharvest) table 3 and (preharvest-postharvest) table 4 were not pooled because the panel evaluations were conducted in the fall and spring, times having substantially different implications for student participation.

Table 4.--*Preharvest and postharvest esthetic evaluation of shelterwood cut and clearcut areas at Coram*

Harvest method	Understory	Camera orientation	Mean rating[1] Preharvest	Postharvest
Shelterwood	Weed-and-bundle (11-3)	Uphill	5.26	--
		Downhill	5.46	--
	Undisturbed (11-4)	Uphill	5.75	--
		Downhill	5.13	--
Shelterwood	Weed-and-bundle (21-3)	Uphill	6.40	4.33
		Downhill	4.70	3.83
	Undisturbed (21-4)	Uphill	6.06	4.60
		Downhill	5.73	5.11
	Slashed (21-1)	Uphill	--	3.24
		Downhill	--	3.54
	Slashed (21-2)	Uphill	--	3.99
		Downhill	--	3.48
Clearcut	Weed-and-bundle (13-3)	Uphill	--	--
		Downhill	--	1.89
	Unprotected (13-4)	Uphill	--	3.85
		Downhill	--	1.75
	Slashed (13-1)	Uphill	--	2.04
		Downhill	--	1.79

[1]A difference of 1.12 between any two numbers in this table is statistically significant at the 0.05 level. Smaller differences between pooled judgments, as reported in the text, are significant.

OTHER CORAM STUDIES

Several other exploratory tests have been run on the Coram Experimental Forest as preliminary steps in developing techniques for assessing the esthetic values of leave strips between forest roads and harvested areas, of forest roads themselves, and of distant views of harvested areas. These tests were based on adaptations of the previously discussed near-view methodology.

Leave strip analysis.--A study was undertaken to determine the effects of leave strips between the observer and the cutting units after harvesting. Photographs were taken defining five subjectively determined treatment conditions: no leave strip, light leave strip, and heavy leave strip next to a clearcut block (block 13), and presence or absence of a leave strip next to a shelterwood block (block 21). Ratings of these slides were obtained from 28 students; mean ratings are presented in table 5.

For the clearcut block, the greater the amount of leave strip the greater the preference. This was not true for the shelterwood block, probably because a large number of the slides with the leave strip contained views of a road in the foreground,

Table 5.--*Evaluations of leave strips adjacent to clearcut and shelterwood cut areas*

Treatment	Leave strip	Mean rating
Clearcut Block 13	Heavy leave strip	4.46
	Light leave strip	2.98
	No leave strip	1.19
Shelterwood Block 21	Leave strip present	3.92
	No leave strip	4.33

while those without the leave strip did not. The subsequent comparisons were correlated almost perfectly with the presence or absence of the road in the photographs: we hypothesize the presence of the road led to lowered ratings.

Near-view road study.--Photographs were taken of four different road sections by first shooting along the road and then pivoting the camera 45° between shots until a circle was completed. Evaluations indicated the most preferred road segment was a section of an old road with established vegetation. As more bare earth and rock and less vegetation were included in the slides, ratings decreased. This conclusion held both for individual slides taken at one point and for groups of slides taken on different road segments.

Far-view study.--To this point, all reported work was based on photographs taken in or at the edge of treated areas. However, distant views predominate in the mountainous regions of northwestern Montana. This study was an exploratory attempt to determine how to best evaluate the esthetic values of such views of the Coram logging treatments.

Photographs were taken from the ground and from a helicopter using a 35-mm camera (with a normal lens). From this pool of slides a sample of 39 was shown to a panel of 16 students. These slides were selected as follows:

1. Show at least three different perspectives of each unit both before and after cutting. (Some photographs were made from the air because it was not possible to get enough different perspectives from the ground.)

2. Show only a single treatment, excluding other cutting units and irrelevant scenic backgrounds and foreground foliage.

3. Use only slides of high photographic quality.

All three criteria were to some extent violated, most notably in our inability to exclude areas outside the logged area.

While the perception of a harvested area is influenced by the kind of forest and prominent land features surrounding the area, our interest was centered on evaluating particular harvesting systems. To define the area to be evaluated, supplementary line drawings were made of each photograph showing prominent terrain features; the area of interest was enclosed in a bold, dotted box. The judges were instructed to rate only that portion of the slide that corresponded to the area within the enclosure and to ignore the surrounding land. To provide a reference point, slides taken before harvest as well as after harvest were included. The mean ratings are given in table 6.

Table 6.--*Evaluations of far views of Coram harvesting areas by panels of students and professional foresters (number of slides in parentheses)*

Harvest area	Mean rating			
	Preharvest		Postharvest	
	Students	Professionals	Students	Professionals
Shelterwood Block 11	6.91 (8)	7.21	4.52 (3)	7.20
Shelterwood Block 21	6.55 (8)	7.26	3.82 (3)	6.72
Group selection Block 12	7.34 (5)	7.35	--	--
Group selection Block 22	--	--	2.81 (5)	5.24
Clearcut Block 13	--	--	.81 (4)	4.33
Clearcut Block 23	-	--	1.00 (5)	4.14

Two groups of judges independently evaluated the slides: university undergraduates and a group of foresters attending a professional meeting. While both groups assigned relatively high ratings to the preharvest slides, the professional foresters assigned substantially higher ratings to the postharvest slides than did the students. We hypothesize this was primarily due to the professionals having undergone a 3-hour introduction to many aspects of the experimental work at Coram just prior to their acting as judges. We do not know whether their general technical expertise influenced their evaluation.

The mean scores indicate an esthetic preference for the shelterwood cuttings and a relative dislike for the clearcuts, with the group selections being intermediate. We conducted no statistical testing, however, because of the small number of slides and because of the unknown extent to which the several uncontrolled influences noted above may have altered the ratings.

SUMMARY AND CONTINUING RESEARCH

The results reported in this paper have been obtained from several case-study areas. Because most of the comparisons made between cut and uncut stands represent radically different conditions of the forest, our test results generally agree with our intuition: as the amount of downed wood or the evidence of man's activities increases, forest scenes are liked less by most observers. As we explore more subtle differences among scenes, it is likely that the testing procedure will lead to less "obvious" conclusions.

We are beginning a study to determine the manner in which esthetic judgments change as vegetation changes after timber harvesting. The study will include periodic evaluations of the harvested areas on the Coram Experimental Forest and on the Teton National Forest.

Within any particular scenic view, we are trying to define the functional relationship between like-dislike evaluations and specific features of those views. The current experimental technique utilizes choices among simultaneously projected pairs and triads of pictures.

Finally, distant-view evaluation techniques are being developed. Given the rugged topography in the Northern Rockies, we feel such techniques will be the most useful of all in providing information for the further development of generalized land management guidelines.

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Research Note INT-204
1976

SPONTANEOUS AND PILOTED IGNITION OF CHEATGRASS

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ABSTRACT

Spontaneous and piloted ignition of cheatgrass (Bromus tectorum *L.*) *stems were investigated in an isothermal atmosphere. Three levels of sample moisture content were tested and minimum heat flux intensities required to produce ignition, times to ignition, and surface temperatures at time of ignition were recorded. Piloted ignition occurred at lower flux intensities and in less time than did spontaneous ignition. A significant difference in delay time to ignition was found to exist for sample moisture contents above 5.4 percent.*

OXFORD: 431.5
KEYWORDS: forest fuel ignition, ignition, pilot ignition, spontaneous ignition, cheatgrass ignition

Cheatgrass (*Bromus tectorum* L.) was introduced into North America from Europe about 1850 and rapidly spread across western rangelands until today it covers an estimated 60 million acres in the 11 western States (Hull 1965). A highly flammable fuel, cheatgrass supports an almost explosive rate of fire spread under low fuel moisture and high wind conditions (Barrows 1951; Klemmedson and Smith 1964). Many fires start in cheatgrass and burn thousands of acres of rangeland each year.

Ignition temperatures of fuels, such as cheatgrass, must be known if fire spread models (Rothermel 1972) and ignitibility criteria (Anderson 1970) are to be used to appraise fire potential of forest and range fuels. This information is also needed for use in fire prevention, hazard control, and in law enforcement when establishing responsibility for fire starts. The advent of the catalytic converter and the higher exhaust temperatures of the newer model automobiles make the need for this information even more pressing. A study of ignition properties of fine forest fuels at the Northern Forest Fire Laboratory included cheatgrass as one of the fuels to be examined. The results of this portion of the study are reported in this paper. Results of similar studies on pine needles have been previously reported (Stockstad 1975).

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[1] The author is research forester stationed in Missoula, Montana, at the Northern Forest Fire Laboratory.

OBJECTIVES AND PROCEDURES

The objectives of this study were to determine (1) the time required for ignition to occur, (2) the surface temperature at the onset of ignition, and (3) the effect of fuel moisture content and initial heat source intensity on (1) and (2). The Stockstad-Lory ignition furnace (Stockstad and Lory 1970; Stockstad 1972, 1973) was used for all testing. Both spontaneous and piloted ignition were studied using a 2.54-cm (1-inch) by 0.14-cm (0.055-inch) section of cured cheatgrass stem section.

Cheatgrass stem sections were passed through a 0.14-cm (0.055-inch) "go-no-go" gage to obtain samples of uniform diameter. Uniform sample length was obtained by cutting sections from stems of desired diameter with a miniature circular saw driven by a modified high-speed hand tool. All samples were kept at ambient air temperature of 22° to 24° C prior to testing.

Temperature of the cheatgrass sample was measured by a 3-mil platinum versus platinum 10-percent rhodium thermocouple placed on the forward end of the sample. The ignition chamber temperature was measured by a similar thermocouple approximately 3 mm from the sample thermocouple (Stockstad 1972). Both thermocouples were connected to a recorder and their output plotted against time.

Stem sections of cheatgrass were placed in conditioning cabinets containing saturated salt solutions (Schuette 1965) to provide three moisture levels (5.4, 10.1, and 18.6 percent). Spontaneous and piloted ignition tests were replicated 20 times for each moisture level and furnace temperature. Moisture content was determined on an ovendry weight basis by using both the conventional ovendry method and the vacuum ovendry method.

The minimum furnace temperature used for each moisture content in the testing program was that at which no ignitions were observed in 20 trials. Furnace temperature was then raised 10° C and another series of 20 tests observed. This procedure was repeated until a furnace temperature was reached at which 100 percent of the samples ignited.

Three points on the thermocouple traces from a spontaneous ignition test were considered in the analysis (fig. 1):

1. The point at which the sample temperature trace crossed and exceeded the ignition chamber trace was considered to be the beginning of the exothermic reaction.

2. The second significant change in the sample trace was the point where the exothermic reaction increased in intensity, resulting in an abrupt rise in the temperature of the sample. This point was considered to be the time and temperature at which the spontaneous ignition process would continue to the end result--visible glowing.

3. An event marker activated by the test operator indicated the time and temperature at which visible glowing was observed. Tests indicated that operator reaction time was one-half second; so this correction was subsequently applied to determine actual glowing ignition time and temperatures.

Pilot ignition tests were conducted in the same manner as spontaneous ignition tests, except for the introduction of a pilot flame (Stockstad 1972). Pilot ignition usually occurred at temperatures below actual furnace temperature; therefore, the beginning of the exothermic reaction, if one occurred, could not be determined by the previously described criteria. The point at which flaming ignition took place was marked by an abrupt, nearly vertical rise in the trace. For this reason, an operator-activated event marker was not necessary for the pilot ignition testing.

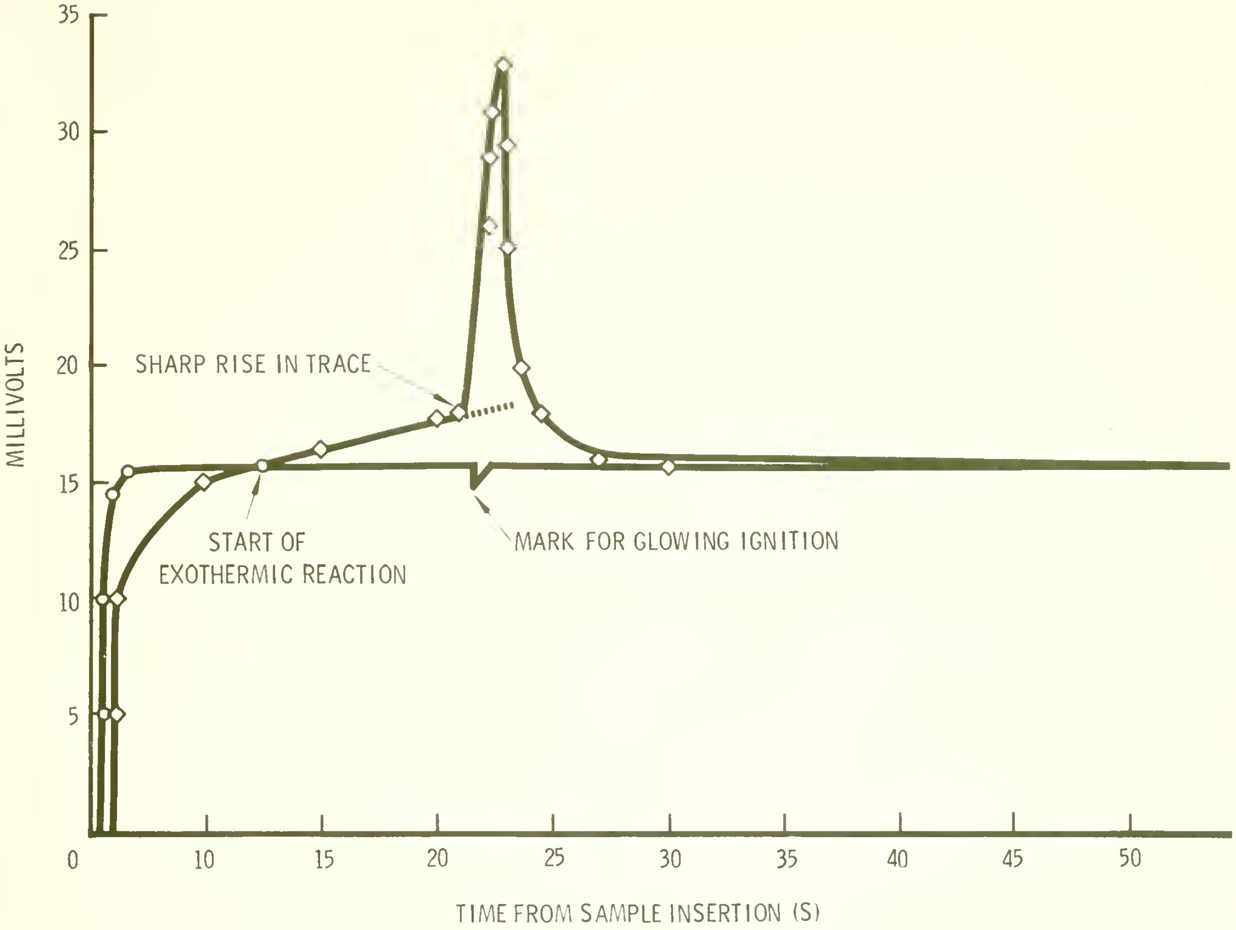

Figure 1.--Sample (◇) and ignition chamber (O) thermocouple traces from a spontaneous ignition test of a 2.54- by 0.14-cm section of cured cheatgrass stem.

PREDICTION OF HEATING RATES

Calculations were made to determine the heat transfer coefficients existing in the furnace during heating of the cheatgrass stem sections. Heating curves were calculated for a furnace temperature of 460° C. Values from this curve were later used to determine the total heat flux necessary to produce ignition. The assumption was made that the cheatgrass stem section would possess properties similar to those of a cylinder in parallel flow. Based on this assumption, the chart plotted by Heisler (1947) was used to obtain values for the Fourier number needed in the calculations.

Formulas used in the calculations were:

$$\theta = \frac{t_o - t_f}{t_i - t_f} = \text{a dimensionless temperature ratio} \qquad (1)$$

$$N_{Fo} = \frac{\alpha\tau}{r_1^2} = \text{Fourier number} \qquad (2)$$

(con. next page)

$$1/N_{Bi} = \frac{K}{hr_1} = \text{Biot number} \tag{3}$$

where

t_o = sample temperature, °F at time t

t_f = furnace temperature, °F

t_i = ambient temperature, °F

τ = time from insertion of sample, seconds

$h = h_r + h_c$ = total heat flux for furnace at any given temperature, cal/cm^2 - °C.

where

h_r = radiant flux and h_c = convective flux

r_1 = radius of cheatgrass stem = 0.071 cm (0.028 inch)

K = thermal conductivity of cheatgrass stem

= 2.35×10^{-4} cal/cm^3 - sec, °C (Byram 1952)

α = thermal diffusivity of cheatgrass stem

= 1.059×10^{-3} cm^2/sec, which was calculated from:

$$\alpha = \frac{K}{\rho C_p}$$

where

ρ = 0.66 gm/cm^3 (Brown 1970)

C_p = 0.19 cal/gm (Byram 1952).

Assuming various sample temperatures between 38° and 454° C and furnace temperatures of 460° C, τ was calculated and resulting values were tabulated in appendix table 1. These values are also plotted in figure 2, together with the curve resulting from the actual heating of a cheatgrass stem section.

The actual heating rate was faster than the calculated rate. A possible explanation could be the increase in adsorption of radiant heat flux by the sample as it darkened during the heating process. The heating of organic substances undergoing thermal decomposition is not a simple thermodynamic process; consequently, the use of a single Fourier number may not be applicable as it is for a metal cylinder. It seems likely that minor exothermic processes might begin relatively early as the sample is being heated, thereby contributing to a temperature rise more rapid than would be expected for inorganic materials. The use of a single value for the heat transfer coefficient existing at a given furnace temperature would also account for some of the disparities between the curves.

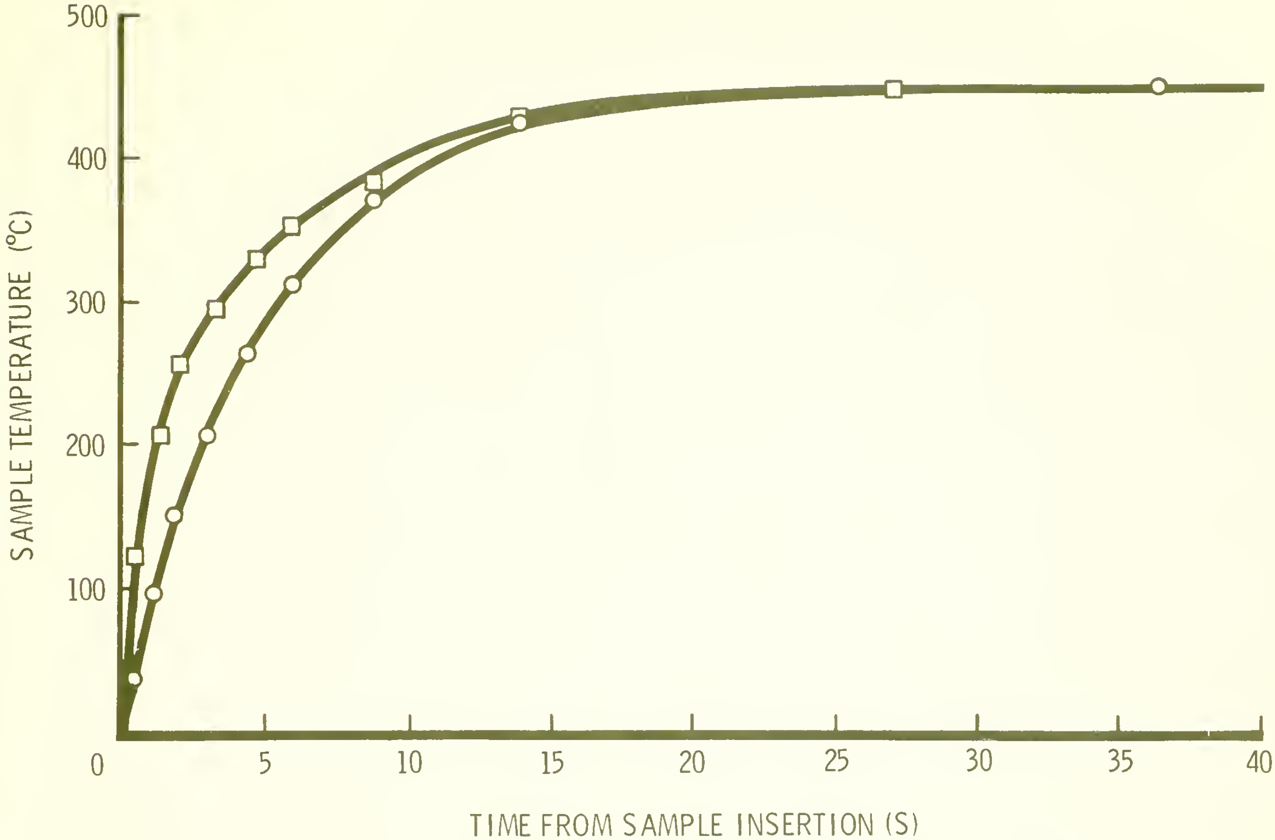

Figure 2.--Calculated (O) and actual (□) time-temperature history of a 2.54- by 0.14-cm section of cheatgrass stem at a moisture content of 5.4 percent during spontaneous ignition at a furnace temperature of 460° C.

RESULTS

The results of the 180 spontaneous ignition tests and the 180 pilot ignition tests are given in appendix tables 2 through 7.

The minimum furnace temperature at which spontaneous ignition occurred was 450° C. A furnace temperature of 460° C was needed to produce spontaneous ignition at all moisture contents tested. A furnace temperature increase from 450° to 460° C increased the probability of ignition from approximately 50 percent to 100 percent.

Figure 3 shows the relationship between the time required for the ignition processes to occur and the moisture contents tested at 460° C, the temperature at which 100 percent ignitions were first obtained.

Analysis of variance at the 95 percent level of confidence did not show a significant difference in the times to glowing ignition or the temperature of ignition for the fuel moisture contents and furnace temperatures examined.

The minimum furnace temperatures at which pilot ignition occurred was 380° C. A furnace temperature of 390° C was needed to produce pilot ignition at all moisture contents tested. As was the case for spontaneous ignition, a 10° C increase in furnace temperature increased the percentage of ignitions from approximately 50 percent to 100 percent.

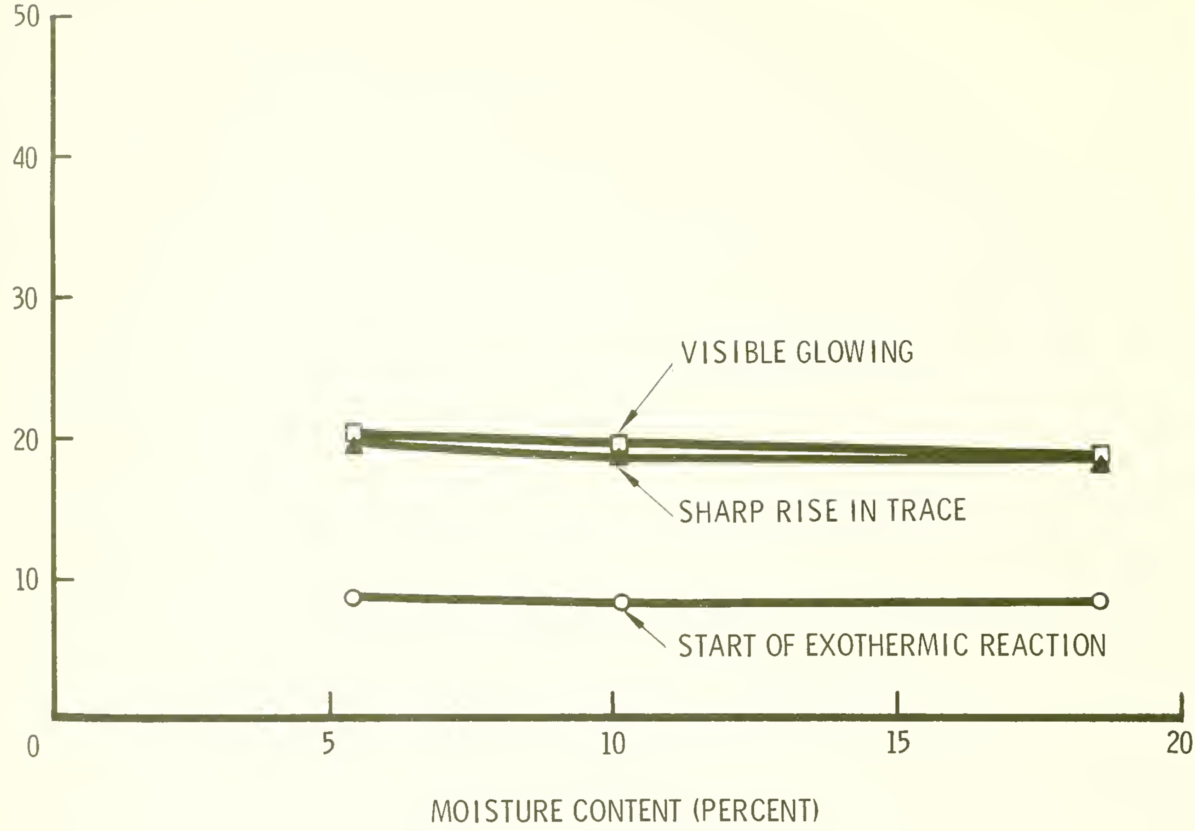

Figure 3.--Ignition time versus moisture content for spontaneous ignition of cheatgrass stem sections at a furnace temperature of 460° C.

The average times required for ignition to occur at various furnace temperatures for the three fuel moisture contents tested are plotted in figure 4. Figure 5 shows the relationship between the time required for ignition to occur and the various moisture contents tested at 390° C, the temperature at which 100 percent ignition occurred. Analysis of variance at the 95 percent level of confidence indicated a significant difference in time to ignition for all fuel moistures and furnace temperatures examined. Further analysis using Tukey's test showed a significant difference in time to ignition between all moisture contents tested.

Analysis of variance at the 95 percent level of confidence did not show a significant difference in the ignition temperatures obtained.

Spontaneous ignition occurred at a minimum flux intensity of 0.75 cal/cm^2-s, although 0.79 cal/cm^2-s was necessary before ignition took place at all moisture contents tested. Pilot ignition occurred at a minimum flux intensity of 0.56 cal/cm^2-s; 100 percent of all samples tested ignited at intensities of 0.57 cal/cm^2-s.

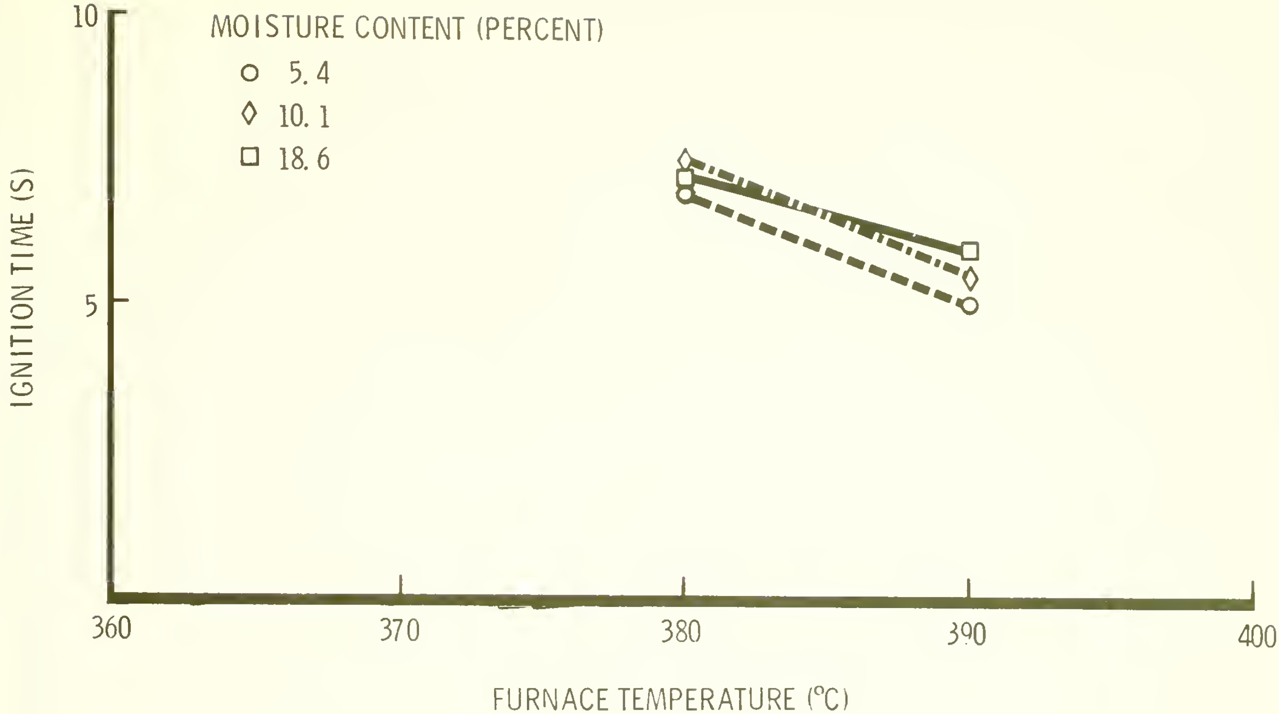

Figure 4.--Ignition time versus furnace temperature for pilot ignition of cheatgrass stem sections for various moisture contents.

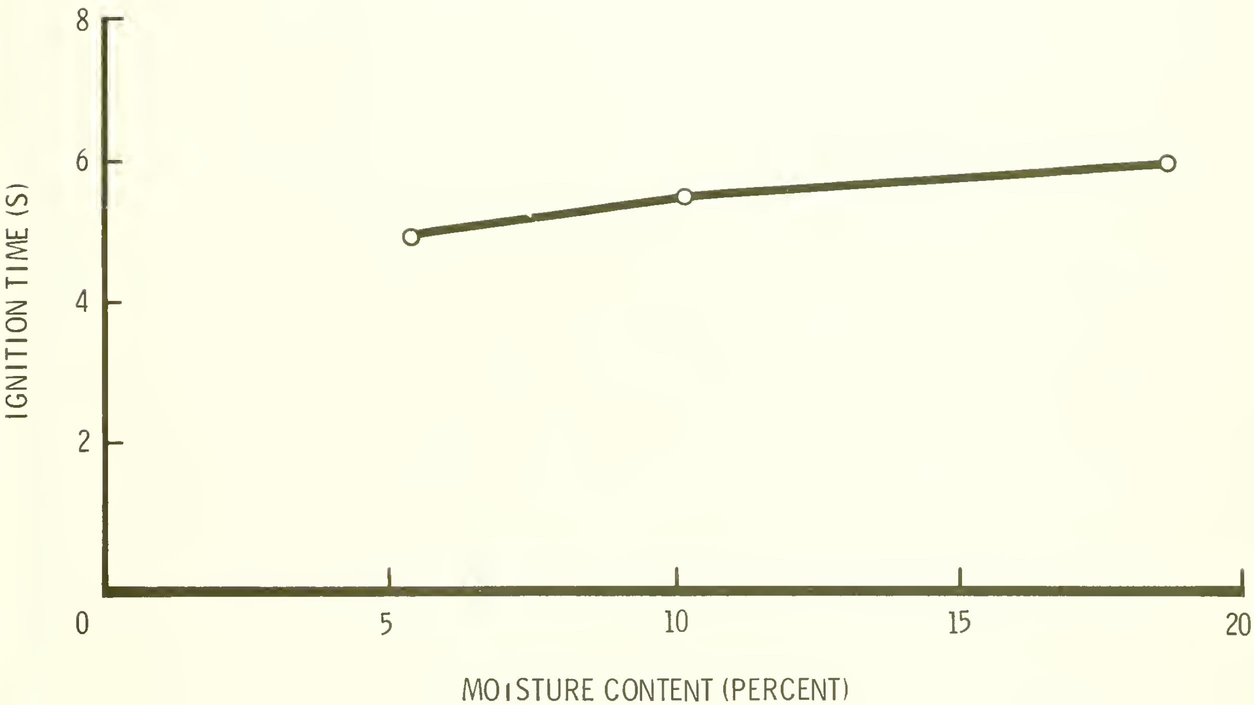

Figure 5.--Ignition time versus moisture content for pilot ignition of cheatgrass stem sections at a furnace temperature of 390° C.

DISCUSSION OF RESULTS

The total heat transfer coefficient for furnace temperatures of 450° and 460° C for each sample moisture content was calculated and is tabulated in appendix table 8. The average temperature for each 20 tests at which the exothermic reaction was considered to begin is also listed. From these values, an average heat transfer coefficient and exothermic temperature were determined. The total heat flux needed to produce spontaneous ignition at all moisture contents tested was then calculated to be 5.8 cal/cm^2 or a total of 18.6 calories. By using this value, an average ignition delay time of 9.5 seconds was calculated. The actual average ignition delay time was also 9.5 seconds.

If a pilot flame is present, the total heat flux necessary to produce ignition is altered considerably. The total heat transfer coefficient for furnace temperatures of 380° and 390° C for each sample moisture content was calculated and is listed in appendix table 9. Also listed in this table is the average temperature for each 20 tests at which flaming ignition occurred. The average heat transfer and ignition temperature were then determined. The total heat flux necessary to produce flaming ignition was calculated to be 2.7 cal/cm^2, or a total of 7.8 calories. The average ignition delay time was calculated to be 6.3 seconds, compared to an actual average ignition delay time of 6.2 seconds.

CONCLUSIONS

Based on the results, certain general conclusions can be drawn concerning ignition of cheatgrass stem sections when heated to ignition in an isothermal atmosphere. In the absence of a pilot flame, spontaneous ignition will occur at moisture contents up to at least 18.6 percent if the igniting agent is capable of producing a heat flux intensity of 0.79 cal/cm^2-s for 9.5 seconds. In the presence of a pilot flame, ignition will occur at moisture contents up to at least 18.6 percent if the igniting agent is capable of producing a heat flux intensity of 0.57 cal/cm^2-s for a period of 6.3 seconds.

A significant difference at the 95 percent level of confidence in delay time to ignition was shown to exist for pilot ignition for cheatgrass stem section moisture contents above 5.4 percent. From this, we conclude that the probability of an ignition occurring decreases as the moisture content rises above 5.4 percent.

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APPENDIX

Table 1.--*Calculated and actual time for a cheatgrass stem section to reach a given temperature at a furnace temperature of 460° C*

Stem section temperature (°C)	460° C furnace temperature	
	Calculated time	Actual time
	- - - - *Seconds* - - - - -	
38	0.5	0.2
93	1.4	.4
149	1.9	.6
204	3.2	1.5
260	4.6	2.4
316	6.0	4.3
371	8.8	7.3
427	13.8	13.5
454	36.4	27.0

Table 2.--*Percentage of spontaneous ignitions of cheatgrass stem sections at selected furnace temperatures for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture content		
	5.4	10.1	18.6
440	0	0	0
450	50	60	55
460	100	100	100

Table 3.--*Time to spontaneous ignition of cheatgrass stem sections at selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Start of exothermic reaction: Percent moisture content			Sharp rise in trace: Percent moisture content			Visual glowing: Percent moisture content		
	5.4	10.1	18.6	5.4	10.1	18.6	5.4	10.1	18.6
	- -			- - - *Seconds* - - -			- -		
440	--[1]	--	--	--	--	--	--	--	--
450	11.6	10.0	10.1	31.4	23.6	40.3	31.4	23.6	40.4
460	8.7	8.3	8.3	19.8	18.5	18.4	20.0	19.4	18.5

[1] Dashed lines indicate no ignition occurred.

Table 4.--*Temperatures at time of spontaneous ignition of cheatgrass stem sections averaged for 20 tests per furnace temperature and varying moisture contents*

Furnace temperature (°C)	Start of exothermic reaction			Sharp rise in trace			Visual glowing		
	Percent moisture content			Percent moisture content			Percent moisture content		
	5.4	10.1	18.6	5.4	10.1	18.6	5.4	10.1	18.6
	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - -	*°C*	- - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
440	--[1]	--	--	--	--	--	--	--	--
450	403	389	382	406	405	409	406	406	411
460	398	392	395	421	414	420	424	419	422

[1] Dashed lines indicate no ignition occurred.

Table 5.--*Percentage of pilot ignitions of cheatgrass stem sections for selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture contents		
	5.4	10.1	18.6
370	0	0	0
380	55	65	60
390	100	100	100

Table 6.--*Time to pilot ignition of cheatgrass stem sections for selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture contents		
	5.4	10.1	18.6
	- - - -	*Seconds*	- - - - -
370	--[1]	--	--
380	6.9	7.2	7.2
390	4.9	5.4	6.0

[1] Dashed lines indicate no ignition occurred.

Table 7.--*Temperatures at time of pilot ignition of cheatgrass stem sections at selected furnace temperatures averaged for 20 tests per moisture content*

Furnace temperature (°C)	Percent moisture contents		
	5.4	10.1	18.6
	- - - - - -	*°C*	- - - - - -
370	--[1]	--	--
380	317	316	321
390	322	319	326

[1] Dashed lines indicate no ignition occurred.

Table 8.--*Average heat transfer coefficient (h) and temperature at initiation of exothermic reaction during spontaneous ignition of cheatgrass stem sections for 20 tests per moisture content at selected furnace temperatures*

Furnace temperature (°C)	Sample moisture content	h	Start of exothermic reaction
	Percent	*Cal/cm²-°C*	*°C*
450	5.4	0.019	403
	10.1	.017	389
	18.6	.017	382
460	5.4	.015	398
	10.1	.014	392
	18.6	.014	395
Average of all tests:		.016	393

Table 9.--*Average heat transfer coefficient (h) and temperature at flaming ignition during pilot ignition of cheatgrass stem sections for 20 tests per moisture content at selected temperatures*

Furnace temperature (°C)	Sample moisture content	h	Flaming ignition
	Percent	*Cal/cm²-°C*	*°C*
380	5.4	0.010	317
	10.1	.010	316
	18.6	.010	321
390	5.4	.007	322
	10.1	.009	319
	18.6	.009	326
Average of all tests:		.009	320

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USDA Forest Service
Research Note INT-205
1976

REVISED MARSH FUNNEL CALIBRATIONS FOR MEASURING FIRE RETARDANT VISCOSITY

Charles W. George and Cecilia W. Johnson[1]

ABSTRACT

Updates data (Research Note INT-91) for measuring viscosity of fire retardants in the field by means of the Marsh Funnel. New data cover Tenogum and gum-thickened Fire-Trol 931. Data for Gelgard (no longer available) have been dropped.

OXFORD: 432.3, 843.1
KEYWORDS: aerial fire suppression, chemical fire retardants, viscosity testing, retardant quality control

In 1966, the Marsh Funnel was first modified so that the viscosity of forest fire retardants could be quickly and inexpensively determined in the field (George and Hardy 1966, 1967).

Because of changes in the retardants and formulations, procedures for measuring viscosity were revised in 1969 (George and Hardy 1969). Since then, retardants or their formulations have continued to change. This research note presents recent revisions in calibration and test procedures.

The calibration data were obtained by comparing viscosities from the Brookfield Viscometer with the flow-through times for the Marsh Funnel; thus, "Marsh-Funnel time" serves as an inexpensive method for determining viscosity (fig. 1).

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[1] Research forester and physical science technician, stationed at Northern Forest Fire Laboratory, Missoula, Montana.

Figure 1.--Determining viscosity with a Marsh Funnel.

INSTRUCTIONS FOR USING THE MARSH FUNNEL

1. Place the appropriate tip in the Marsh Funnel.
2. Use only fresh samples that have stabilized; i.e., excessive air bubbles have disappeared and complete hydration has occurred (approximately 1/2 to 1 hour after mixing).
3. Cover the funnel tip with a finger and pour the retardant *through* the screen into a clean, dry, upright funnel until the fluid level *exactly* reaches the bottom of the screen.
4. Measure the time in minutes and seconds for 1 quart (946 ml) of retardant to flow through the funnel--the funnel holds approximately 2 quarts (1,892 ml).
5. Look up measured time on left-hand side of table. Read proper column to the right to find viscosity in centipoise.

NOTE:

1. Keep in mind that time elapsed since agitation and retardant temperature influence viscosity. The viscosity found in the table will apply to the retardant only at the time and temperature at which the sample is tested.
2. For the samples tested in the laboratory, the Marsh Funnel method gave viscosities within 5 percent of the Brookfield method.
3. Numbers included within the boxes indicate the normal use ranges.

MARSH FUNNEL TIME - FIRE RETARDANT VISCOSITY RELATIONSHIPS[1]
REVISED 1976

Time for 1 qt (946 ml) to flow thru funnel[2] (min:sec)	Tenogum	Phos-Chek XA	Phos-Chek 259	Fire-Trol 100	Fire-Trol 100	Fire-Trol 931 gum-thickened[4]	Fire-Trol 931 concentrate
	lg tip[3]	lg tip	sm tip[3]	lg tip	sm tip	lg tip	lg tip
	-Centipoise-						
0:10							
:15	310			930		147	
:20	532	557		1530		473	
:25	703	767		1900		727	
:30	843	966	5	2140		934	
:35	962	1155	20	2330		1109	
:40	1065	1334	43	2480	920	1260	
:45	1155	1502	66	2590	1110	1394	
:50	1236	1659	89	2680	1250	1514	
:55	1310	1806	112	2750	1370	1622	
1:00	1377	1942	136	2800	1460	1721	1900
:05	1438	2067	159	2840	1541	1811	
:10	1495	2183	182	2880	1610	1896	
:15	1548	2287	205	2900	1670	1974	
:20	1598	2381	228	2920	1720	2047	
:25	1645	2465	251	2930	1770	2116	
:30	1689	2538	274	2940	1810	2181	
:35	1730		297	2950	1840	2242	
:40	1770		320	2960	1870	2300	
:45	1807		343		1900	2356	
:50	1843		367		1940	2409	
:55	1877		390		1960	2459	
2:00	1910		413			2507	2200
:15	2000					2641	
:30	2081					2761	
:45	2155					2869	
3:00	2222					2968	2500
:15	2283					3059	
:30	2340						
:45	2393						
4:00	2443						2800
:15	2490						
:30	2534						
:45	2575						
5:00	2615						3100
6:00							3400
8:00							4000
10:00							4600
12:00							5200

[1] Viscosities by Brookfield Model LVF, at 60 r/min, spindle 4 (for viscosities of more than 500 cP) or spindle 2 (for viscosities from 1-500 cP); at a temperature of 65-75° F, higher temperatures may give false low viscosities, lower temperatures may give false high viscosities.

[2] Funnel must be full to screen before testing begins.

[3] Large tip diameter should be 0.269 ±0.002 inch; small tip inside diameter should be 0.187 ±0.002 inch.

[4] Viscosity is dependent upon age of gum, storage time and conditions, and degree of agitation prior to use.

The revised table published here includes only products currently being used. New products (since the last revision) are Fire-Trol 931 (LC), gum-thickened Fire-Trol 931, and Tenogum. The formulation of Phos-Chek XA (replacement for 202 or 202 XA) has been altered, although no change in the calibration has been necessary. The viscosity of unthickened, diluted Fire-Trol 931 does not change significantly with the change in dilution rate, and its low viscosity limits the usefulness of Marsh Funnel measurements. (Fire-Trol 931 diluted with water at the rate of four parts water to one part concentrate yields a solution with a Brookfield viscosity of approximately 70 centipoise, or 12 Marsh-Funnel seconds.)

The Marsh Funnel packet is still available. It contains the table, instructions for converting a Marsh Funnel, and a list of commercial sources. Separate tables and the packet can be ordered from the Northern Forest Fire Laboratory, Intermountain Forest and Range Experiment Station, Drawer G, Missoula, Montana 59801.

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U.S. GOVERNMENT PRINTING OFFICE: 1976-O-677-328/58