Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-51

1966

SOME CAUSES OF NATURAL TREE MORTALITY IN OLD-GROWTH PONDEROSA PINE STANDS IN WESTERN MONTANA

Philip C. Johnson [1]

ABSTRACT

Natural phenomena capable of quick-killing (within 1 year) mature ponderosa pine trees in western Montana were studied from 1948 to 1965. Of the 406 trees that had died of the 10,600 pine trees observed during this period, 57 percent had died from the effects of windstorms, 27 percent from attacks by bark beetles of the genus *Dendroctonus*, 7 percent from other but unknown causes, 6 percent from attacks by phloem-feeding insects other than *Dendroctonus*, and 3 percent from lightning strikes. The mean annual mortality of pine covered by these causal categories amounted to 78 board feet per acre.

The identity and importance of natural phenomena that kill ponderosa pine trees usually within 1 year were studied in western Montana between 1948 and 1965. So-called quick-acting causes considered in the study were: (1) fire; (2) windstorms; (3) lightning; (4) flooding; (5) land displacement from underground seepage or earthquake shocks; (6) damage from animals; (7) sudden concentrations of airborne pollutants; (8) defoliating insects, such as the pine butterfly, *Neophasia menapia* Felder and Felder (Lepidoptera: Pieridae); (9) bark beetles of the genus *Dendroctonus* (Coleoptera: Scolytidae); (10) certain other phloem-feeding beetles, principally *Ips pini* (Say) (Coleoptera: Scolytidae) and *Melanophila californica* Van Dyke (Coleoptera: Buprestidae); and (11) other but unknown causes.

[1] Principal Entomologist, headquartered at Intermountain Forest and Range Experiment Station, Missoula, Montana.

Tree killing by some of these causal factors is independent of predisposing influences that may weaken or damage the trees. Other causes of killing are effective only after the vigor of the trees has been reduced by environmental deficiencies, pathogens, or physical injuries. Hence, they may be termed "primary" or "secondary" causes of tree death depending on the degree of tree vigor they must overcome.

PROCEDURE

Pine tree mortality was recorded annually from 1948 to 1965 from an original selection of 10,600 mature, living ponderosa pine trees 12 inches diameter breast height and over. The trees were distributed throughout 34 plots established in representative old-growth ponderosa pine stands in Montana west of the Continental Divide between 1948 and 1959. The pine timber on 21 plots remained in a virgin state throughout the study. On 13 plots, it was subjected to selection cuttings that were considered light enough not to influence the nature and rate of mortality of the residual trees.

Dead trees were felled and limbed shortly after their discovery. These were carefully examined externally and internally to determine probable cause of death. The internal examination consisted of a stem analysis for which sections of the bole cambium were systematically exposed from the base to the top of the tree.

RESULTS

A total of 406 ponderosa pine trees died on the study plots between 1948 and 1965 from the effects of windstorms, bark beetle attacks, other but unknown causes, attacks of other phloem-feeding insects, and lightning strikes (table 1).

Trees were killed in the following ways:

Windstorms.--Trees were uprooted or their trunks were broken off below the bottom of the crowns by winds.

Bark beetles.--Lethal attacks on the boles of the trees, principally by the western pine beetle, *Dendroctonus brevicomis* LeConte, but also occasionally by the mountain pine beetle, *D. ponderosae* Hopkins.

Lightning strikes.--Trees not shattered or fired by lightning strikes, as sometimes happens, but marked with a narrow strip of exposed cambium parallel to the grain of the sapwood indicating the course of the electrical charge between the top and base of the trees. Most of the lightning-struck trees observed during the study were heavily attacked by the first subsequent flight of emerged *Dendroctonus* beetles.

Other phloem-feeding insects.--Lethal attacks on the boles of the trees, chiefly by the pine engraver, *Ips pini*, and the California flatheaded borer, *Melanophila californica*.

A distinction was made in the study between bark beetles of the genus *Dendroctonus* and the other phloem-feeding insects because the two groups represent different problems in the protection of ponderosa pine forests. Bark beetles traditionally kill more trees in stands of mature ponderosa pine over a period of time than do the pine engravers or flatheaded borers.

Table 1.--Mature ponderosa pine trees 12 inches d.b.h. and over killed on 34 plots in western Montana between 1948 and 1965

Causal agent	Trees killed		Volume killed[1]	
	Number	Percent	Gross bd. ft.	Percent
Windstorms	231	56.9	208,360	57.0
Bark beetles	121	29.8	97,830	26.7
Lightning	16	4.0	28,120	7.7
Unknown causes	18	4.4	21,290	5.8
Other insects	20	4.9	10,250	2.8
Total	406	100.0	365,850	100.0

[1] Scribner Decimal C volume table.

The pine engravers ordinarily attack and kill only the smallest of the mature pine trees. These are populations that usually have developed from pine slash or snow breakage that has accumulated in the forest. Attacks by Ips are more indiscriminate and usually less predictable, whereas those by bark beetles generally are more selective. Trees susceptible to D. brevicomis, for instance, can usually be identified with considerable accuracy in many parts of the Western United States by applying the Ponderosa Pine Risk Rating System.[2] This system's effectiveness is currently under investigation in western Montana.

Trees killed by lightning strikes alone were not observed during the study. A few trees were found that had been struck, but these showed no visible sign of damage other than the telltale narrow strip of exposed cambium marking the course of the electrical charge.

The 16 trees classified in table 1 as lightning-killed constituted about 80 percent of all those known to have been struck on the plots during the study. Each of the 16 trees was heavily attacked by the first subsequent flight of newly emerged Dendroctonus beetles, primarily those of D. brevicomis. Although these trees presumably died from the direct effects of these attacks, it is doubtful if most of them would have been attacked by Dendroctonus beetles had they not first been struck by lightning.

Only four of the 16 trees were rated as risk 3 or risk 4 according to the risk rating system and hence highly susceptible to attack by the beetles. Because of the great attraction of lightning-struck trees to D. brevicomis,[3] the 16 trees considered here were judged in the study to have died as a result of the predisposing, or primary, effects of the lightning strikes and not from the followup, secondary attacks of the bark beetles.

[2] Salman, K. A., and J. W. Bongberg. Logging high risk trees to control insects in pine stands of northeastern California. J. Forest. 40(7): 533-539. 1942.

[3] Johnson, Philip C. Attractiveness of lightning-struck ponderosa pine trees to Dendroctonus brevicomis (Coleoptera: Scolytidae). Entomol. Soc. Amer. Ann. 59(3): 615. 1966.

The trees killed by the causal agents listed in table 1 were reasonably well distributed throughout the plots and the period covered by the study, except for trees killed by windstorms. Two-thirds of the trees killed by windstorms were concentrated on five of the 34 plots. During the period of the study, each of the five plots had been subjected to at least one localized windstorm of hurricane force that contributed to catastrophic blowdowns of pine timber within and adjacent to the plots. Two of the plots were buffeted by similar winds a second time. Wind-caused tree killing was more evenly distributed over the remaining 29 plots, although it was concentrated in a few locations in a way to suggest that topography might be related to this type of damage.

The year-after-year importance of the tree-killing factors listed in table 1 can be best appreciated from the following tabulation. This shows the annual rate of loss per acre in the ponderosa pine stands covered in this study that could be attributed to each of these factors.

Causal factor	Gross board feet
Windstorms	44
Bark beetles	21
Lightning	6
Unknown causes	5
Other insects	2
	78

The annual loss caused by bark beetles reflects the endemic nature of populations of *D. brevicomis* and *D. ponderosae* that were prevalent in western Montana during the life of the study. Mean annual losses of from 100 to 300 board feet per acre are not uncommon from epidemic populations of *D. brevicomis* in stands of mature ponderosa pine.[4]

[4] Miller, J. M., and F. P. Keen. Biology and control of the western pine beetle. U.S. Dep. Agr. Misc. Pub. 800, 381 pp. 1960.

Research Note

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

U.S. Forest Service
Research Note INT-52

1966

DEVELOPMENT OF PONDEROSA PINE PROGENY IN WESTERN MONTANA

Raymond C. Shearer[1]

ABSTRACT

Ponderosa pine seed production was determined after controlled pollination of four trees and natural pollination of three others. Following 2 years of growth in a nursery, the 1-1 progeny were outplanted in western and eastern Montana. Ten years later, all the trees planted in eastern Montana were dead because of drought. Seedlings from all sources but one outplanted in western Montana survived well. Most of these seedlings grew at comparable rates; chief exceptions were those grown from seed of self-pollinated cones picked near the planting site and seed taken from wind-pollinated cones from eastern Montana.

Geographic source of seed frequently and importantly affects the success of plantations, even within the natural range of the species. One challenge that faces the tree breeder is to identify crosses that will produce trees with hybrid vigor. This study helped identify some crosses that initially survived well and showed good growth characteristics.

PROCEDURE

In 1953, four ponderosa pine (*Pinus ponderosa* Laws.) trees growing on the Lubrecht Experimental Forest[2] in western Montana were selected as seed parents for controlled pollinations.[3] The age, diameter at breast height, and total height of each tree are summarized as follows:

---

[1]Associate Silviculturist, headquartered at Intermountain Forest and Range Exp. Station's Forestry Sciences Laboratory, Missoula, Montana, which is maintained in cooperation with the University of Montana.

[2]Maintained by the University of Montana, School of Forestry, Missoula, Montana.

[3]Study was started, flowers were pollinated, and seed was collected by Anthony E. Squillace, Research Forester, formerly assigned to Intermountain Forest and Range Exp. Station and now assigned to Southeastern Forest Exp. Station. Seedlings were outplanted by David Tackle, Research Forester, formerly assigned to the Intermountain Forest and Range Exp. Station and now assigned to the Pacific Northwest Forest and Range Exp. Station.

Tree number	Age	D.b.h.	Total height
	(Years)	(Inches)	(Feet)
PP1	108	19.5	92
PP2	153	19.0	81
PP3	146	15.0	73
PP4	[1]164+	18.3	68

[1]Heart rot prevented determination of age.

Trees PP1, PP2, and PP4 were selected on the basis of accessibility, fruiting ability, and ease in climbing. Tree PP1 had good growth rate and crown form. Tree PP3 showed superior phenotypic traits, phenomenal growth response to release, and excellent crown form. However, the tree bore few flowers and was not used for hybridization trials. Instead, its few flowers were pollinated from tree PP1 to try to cross two superior phenotypes. Table 1 lists all the crosses attempted.

Flowers were bagged on May 19, 1953, pollinated June 11 to 20, and cones collected September 7, 1954. Metal bands prevented squirrels from climbing the trees. The extracted seeds were winnowed by hand to remove most of the empty seed.

Seed produced in 1954 from these controlled pollinations, together with several lots from wind pollinations, were sown in the Montana State Nursery at Missoula in 1955. During the period May 4-10, 1956, the 1-0 stock was transplanted. The 1-1 seedlings were outplanted May 2, 1957, on the Custer National Forest, and on May 7 and 8, 1957, on the Lubrecht Experimental Forest. Both areas formerly grew ponderosa pine. The study was installed in a randomized block design with three replications at each location. Six trees of each lot were planted in each block. The trees were spaced 6 feet apart.

RESULTS

Seed yield.--Table 1 summarizes the crosses and their resulting seed yields. The crosses that produced best seed yield were: (1) three local ponderosa pine (*P. ponderosa*) seed parents and "eastside" ponderosa pine (*P. ponderosa* var. *scopulorum*) pollen parents from the Custer National Forest; (2) an intraspecies cross between trees PP1 and PP3; and (3) the self-pollination of PP1.

Seed from wind-pollinated cones was available from tree PP2 only. This was surprising because at the time of pollination, trees PP1 and PP4 had numerous flowers that were not used in controlled pollination.

Outplanting survival and development.--Survival was a contrast of extremes between the two study areas. In 1965, 8 years after outplanting on the Lubrecht Experimental Forest, all progenies except PP1 X PP1 had high survival (table 2). Conversely, on the Custer National Forest all trees died by 1962 because of drought; this prevented any comparisons of the progenies by planting site.

The 1965 remeasurement on the Lubrecht Experimental Forest revealed that all seedlings except those from PP1 X PP1 and PP1 X PS (Custer) had similar development (table 2). Figure 1 contrasts the best seedling from PP1 X PP1 (poorest average development) with the best seedling from PP1 X PS (Custer) (best average development). The *P. ponderosa* X *P. ponderosa* var. *scopulorum* hybrids generally had the best development. Because these trees are just beginning maximum growth, any real differences in height, diameter, or crown width will become apparent in future measurements.

Table 1.--Summary of pollination data and seed collections

Seed parent	Pollen parent	Source of pollen	Flowers pollinated	Cones collected	Total sound seed	Sound seeds per cone	Average seed weight	Abbreviated lot designations
			- - - - - - - - - -	-Number-	- - - - - - - -	Av.	Mg.	
P. ponderosa #1	P. ponderosa #1	--	15	14	284	20.3	50.2	PP1 X PP1
P. ponderosa #1	P. ponderosa v. scopulorum	[1]PREF	14	12	±964	80.3	56.2	PP1 X PS(Custer PR)
P. ponderosa #1	P. ponderosa v. scopulorum	[2]Ashland, Mont.	20	15	±922	61.5	53.8	PP1 X PS(Custer)
P. ponderosa #2	Wind	--	--	20	563	28.2	43.4	PP2 X wind
P. ponderosa #3	P. ponderosa #1	--	13	8	498	62.2	38.3	PP3 X PP1
P. ponderosa #4	P. ponderosa v. scopulorum	[3]Ashland, Mont.	17	13	±1,326	102.0	35.2	PP4 X PS(Custer)
P. ponderosa[4]	Wind	--	--	44	±2,515	57.2	42.6	PP(LEF) X wind
P. ponderosa v. scopulorum[2]	Wind	--	--	14	640	45.7	38.1	PS(Custer) X wind
P. ponderosa v. scopulorum[5]	Wind	--	--	16	404	25.2	52.7	PS(Custer PR) X wind

[1]Pollen collected from two trees growing on the Priest River Experimental Forest. The trees are located in racial variation test established in 1911. Their source is Camp Cook, Custer National Forest, elevation 3,100 feet.

[2]A mixture collected on the Fort Howes District, Custer National Forest, elevation 3,800 feet.

[3]Pollen collected from three trees growing on the Fort Howes District, Custer National Forest (from the same stand that the mixture indicated in footnote 2 was collected).

[4]A three-tree mix of seed collected on the Lubrecht Experimental Forest.

[5]A two-tree mix collected on the Priest River Experimental Forest (from the same plot indicated in footnote 1).

Table 2.--Survival and means of height, diameter, and crown width in 1965 of ponderosa pine hybrids planted on the Lubrecht Experimental Forest in 1957

Hybrids of P. ponderosa[1]	Survival	Height	D.o.b.[2]	Crown width
	Percent	Feet	Inches	Feet
PP1 X PP1	33	[3] 1.76	0.48	1.03
PS (Custer) X wind	94	2.00	0.74	1.22
PP3 X PP1	72	2.97	0.86	1.84
PP(LEF) X wind	89	3.40	1.08	1.99
PP1 X PS (Custer PR)	89	3.53	1.08	2.16
PP2 X wind	100	3.66	1.12	2.23
PP1 X PS (Custer)	100	3.69	1.18	2.29
PP4 X PS (Custer)	94	3.41	1.05	2.38
PS (Custer PR) X wind	94	3.44	1.18	2.42

[1] See table 1 for description of seed and pollen parents.

[2] Diameter outside bark at ground line.

[3] Means enclosed by any single bracket are not significantly different at the 5-percent level.

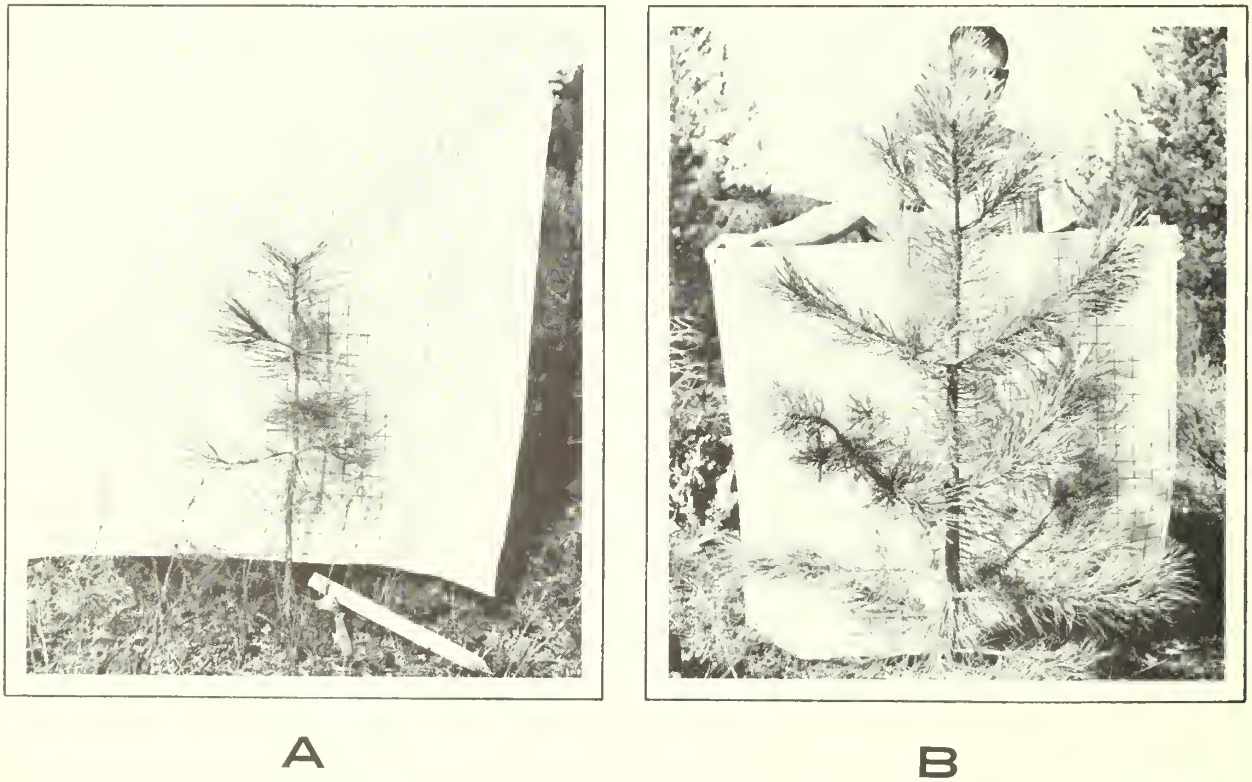


Figure 1.--Comparisons of the best 10-year-old seedlings: (A) PP1 X PP1; (B) PP1 X PS (Custer). Each square is 2 X 2 inches.

AFPS, Ogden, Utah

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-53

1966

PERFORMANCE OF 14-YEAR-OLD PINUS PONDEROSA HYBRIDS IN WESTERN MONTANA

Raymond C. Shearer[1]

ABSTRACT

Ponderosa pine progenies derived from two Montana sources grew better in western Montana than seedlings from seven seed lots from Eldorado County, California, sources. Seedlings from the western Montana source (Kootenai National Forest) had better growth than seedlings from the eastern Montana source (Helena National Forest).

Considerable tree breeding in the Western United States has been directed toward the production of ponderosa pine (*Pinus ponderosa* Laws.) hybrids having better survival, growth, form, or other desirable characteristics. These studies also have given considerable information on the suitability of these hybrids to the varied soils and climatic conditions. This study was conducted to determine if hybrids between the so-called Rocky Mountain form (designated *P. ponderosa* var. *scopulorum* Engelm.) growing east of the Continental Divide, and the Pacific Coast form might be more vigorous than the *scopulorum* parent and might be suitable for planting in the natural range of ponderosa pine in eastern Montana.

Seven lots of ponderosa pine seed were provided for this study by the Institute of Forest Genetics, Placerville, California. The mother trees grew in Eldorado County, California, and were pollinated either by wind or by pollen collected in Colorado from a *scopulorum* parent. Two sources of pine seed from Montana (Kootenai National Forest and Helena National Forest) were added for comparison. The nine seed lots (table 1) were sown at Savanac Nursery in western Montana on May 12, 1950, and transplanted May 17, 1951.[2] Outplantings of the 1-2 stock were established in a randomized block design on May 5, 1953, on the Custer National

---

[1]Associate Silviculturist, headquartered at Intermountain Forest and Range Experiment Station's Forestry Sciences Laboratory, Missoula, Montana, which is maintained in cooperation with the University of Montana.

[2]Anthony E. Squillace, formerly Forester, Intermountain Forest and Range Experiment Station, now with Southeastern Forest Experiment Station, installed this study.

Table 1.--Lot designations assigned by the Institute of Forest Genetics

Seed parent	Pollen parent	Abbreviation
P. ponderosa--Eld.--15-32 (4000' elev.)	X *P. ponderosa* v. *scopulorum*--Colo.	PP 4000' X *scop*.
P. ponderosa--Eld.--15-32 (4000' elev.)	X wind	PP 4000' X wind
P. ponderosa--Eld.--4B-61 (2800' elev.)	X *P. ponderosa* v. *scopulorum*--Colo.	PP 2800' X *scop*.
P. ponderosa--Eld.--4B-61 (2800' elev.)	X wind	PP 2800' X wind
P. ponderosa--Eld.--12-2 (5400' elev.)	X *P. ponderosa* v. *scopulorum*--Colo.	PP 5400' X *scop*.
P. ponderosa--Eld.--12-2 (5400' elev.)	X wind	PP 5400' X wind
P. ponderosa--Eld.--15-32 (4000' elev.)	X *P. engelmannii*	PP X apache
P. ponderosa v. *scopulorum*--Helena N.F.	X wind	*Scop*. (Helena) X wind
P. ponderosa--Kootenai N.F.	X wind	PP (Kootenai) X wind

Forest (eastern Montana) and on May 11, 1953, on the Lubrecht Experimental Forest[3] (western Montana). Three blocks were established at each location, and six trees were planted in each plot. Both areas formerly grew ponderosa pine.

RESULTS

Survival of the planted trees was strongly influenced by the severity of the planting site and by the condition of the seedlings when they were lifted at the nursery. The Custer National Forest plots were abandoned in 1957 because survival had decreased to only 7 percent (inadequate for analysis). These plots were on a very droughty site; this accounted for most of the deaths. However, even on the more favorable site on the Lubrecht Forest all of the seedlings from the wind-pollinated California sources died during the summer following outplanting. Winter damage at the nursery probably caused most of these losses because many seedlings were yellowish when they were lifted. The seedlings from the California sources were tallest prior to outplanting, as shown in the following tabulation:

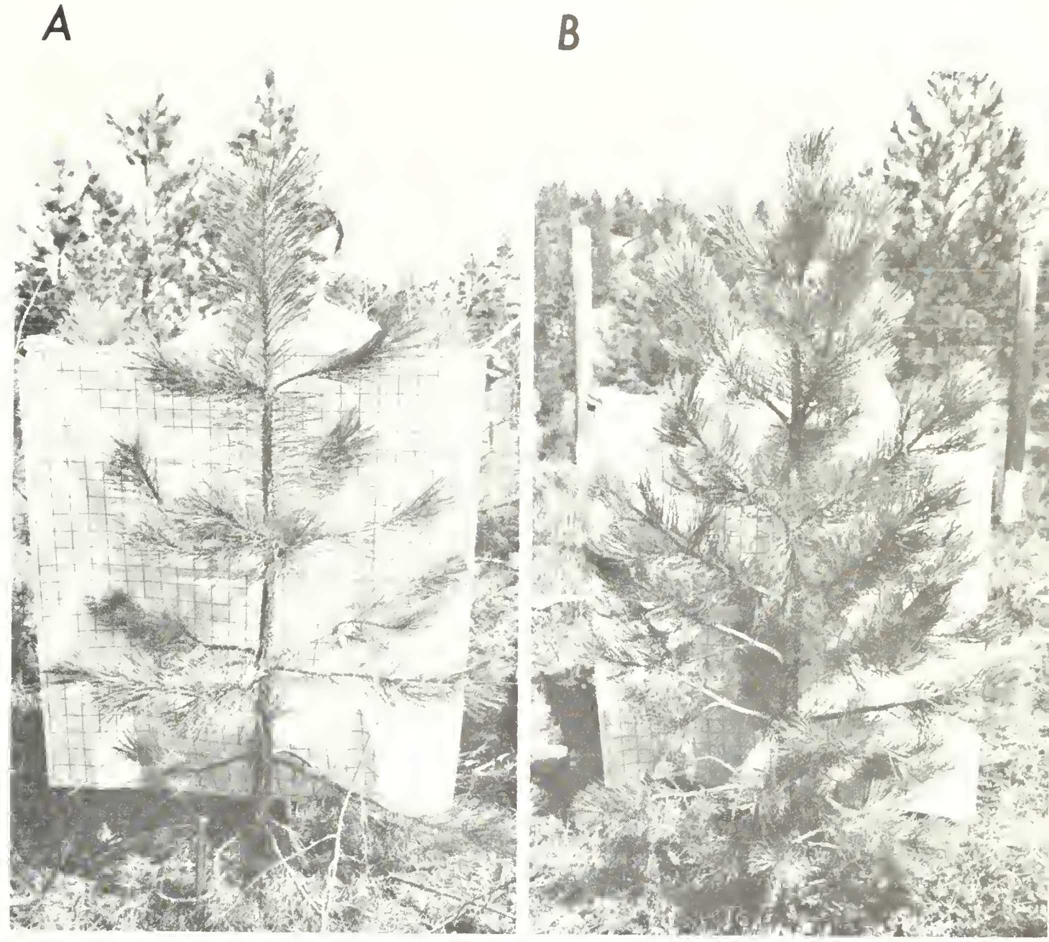
Seed and pollen parent abbreviation	Height (feet)
PP 2800' X wind	0.35
PP 2800' X *scop*.	[1]0.32
PP 4000' X wind	0.32
PP 4000' X *scop*.	0.27
PP 4000' X apache	0.25
PP 5400' X wind	0.29
PP 5400' X *scop*.	0.26
PP (Kootenai) X wind	0.28
Scop. (Helena) X wind	0.26

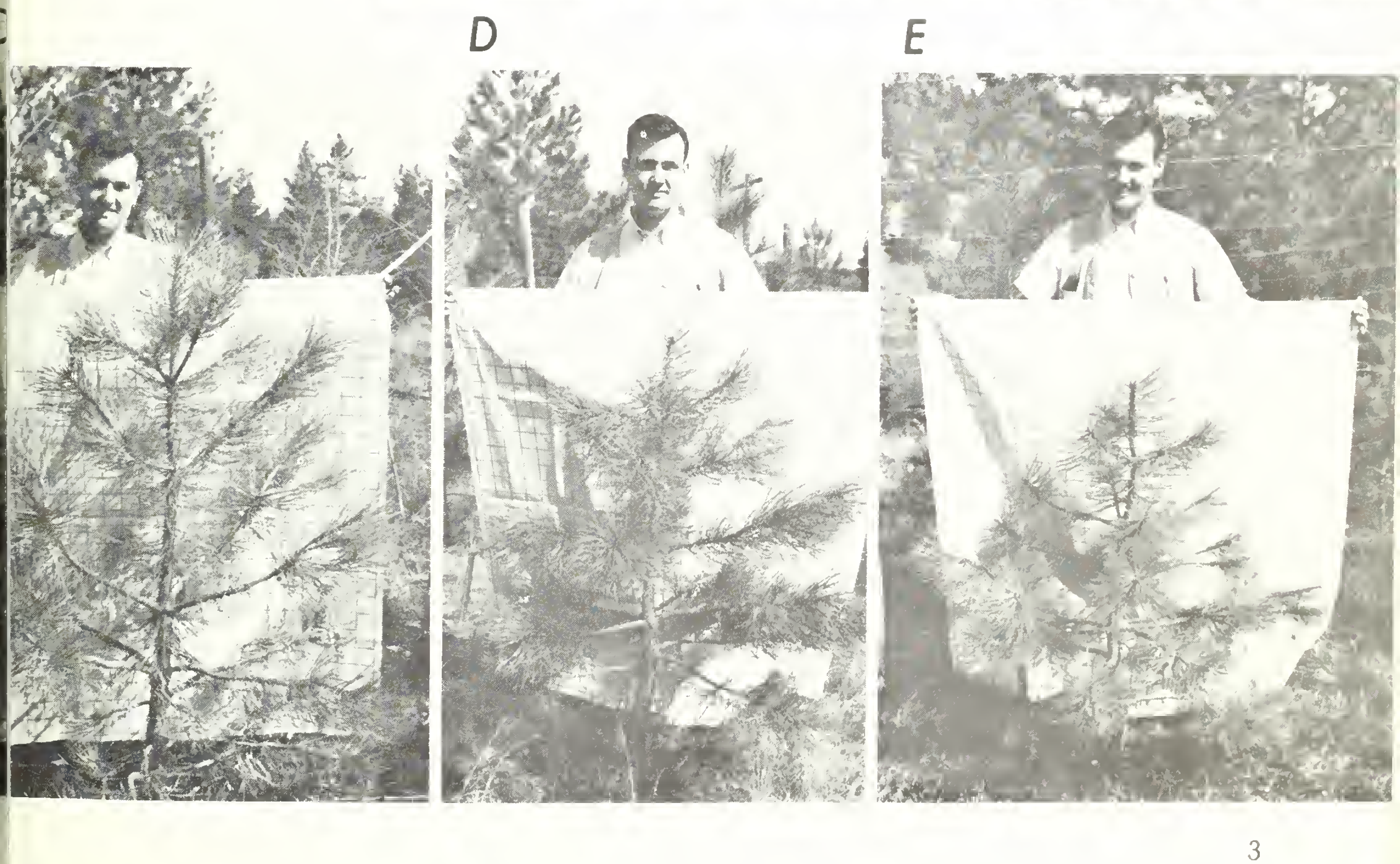
[1]Items underlined in both columns are sources that had surviving seedlings in 1965.

All of the PP X apache seedlings died by 1957.

[3]Maintained by the University of Montana School of Forestry.

igure 1.--Comparisons of the best 15-year-old trees of: A, PP (Kootenai) X wind; B, *scop*. (Helena) X wind; C, PP 5,400' X *scop*.; D, PP 4,000' *scop*.; and E, PP 2,800' X *scop*.





By 1965 the height of surviving seedlings showed almost a complete reversal from the heights measured in 1953 in the nursery (cf. table 2). Seedlings from PP (Kootenai) X wind seed had mediocre initial survival, but by 1965 they had grown significantly larger than seedlings from other sources (table 2). The scop. (Helena) X wind seedlings were taller than the California hybrids and had a greater crown width and diameter outside bark (d.o.b.) than the California progeny grown at elevations of 4,000 and 2,800 feet. Figure 1 shows the best tree from each group that had surviving hybrids.

Height, d.o.b., and crown width increased with elevation of the California seed source (table 2). In 1953 this pattern for height growth was exactly opposite. Growth of the hybrids from the 4,000-foot source did not vary significantly from that of hybrids from the 5,400- or 2,800-foot sources; but growth of seedlings from the 5,400- and 2,800-foot sources differed significantly.

These trees are now growing rapidly, and later measurements will show how well these juvenile traits are maintained.

Table 2.--Mean survival, height, diameter, and crown width in 1965 of seedlings growing on Lubrecht Experimental Forest

Source of P. ponderosa	Survival	Height	D.o.b.[1]	Crown width
	Percent	Feet	Inches	Feet
PP 2800' X scop.	67	[2]2.60	1.30	2.71
PP 4000' X scop.	39	4.30	1.60	3.17
PP 5400' X scop.	67	4.53	1.78	3.42
Scop. (Helena) X wind	94	5.91	1.91	3.86
PP (Kootenai) X wind	50	7.01	2.26	4.51

[1]Diameter outside bark at ground line.

[2]Means connected by the same vertical line are not significantly different at the 5-percent level.

AFPS, Ogden, Utah

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-54 1966

SOIL MOISTURE DEPLETION BY GAMBEL OAK IN NORTHERN UTAH

Ronald K. Tew[1]

ABSTRACT

In years of normal rainfall, 11 to 13 inches of moisture are extracted by Gambel oak from the upper 8 feet of soil during the growing season. The total evapotranspirational loss ranges from 15 to 19 inches, depleting moisture from the entire profile. Early season moisture depletion occurs mainly in the upper 4 feet of soil with losses occurring lower in the profile later in the season. Winter precipitation usually provides sufficient moisture to fully recharge the soil profile after the growing season.

Mountain brush consisting largely of Gambel oak (Quercus gambelii Nutt.) occupies approximately 1 million acres in Utah, mainly at intermediate elevations. Replacing deeply rooted oak brush with plants having shallow root systems may reduce water consumption and increase water yields, particularly on deep soils. Also, fire hazard may be reduced and wildlife habitat improved when these extensive brush fields are broken into smaller units through conversion.

[1] Associate Plant Physiologist, headquartered at Forestry Sciences Laboratory, Logan, Utah, which is maintained in cooperation with Utah State University.

Before recommending this type of action, information was needed concerning the use of water by oak and by potential replacement species. To provide such information research was begun in 1961 to determine the evapotranspirational characteristics of a native Gambel oak stand.

DESCRIPTION OF STUDY AREA

Three plots were established at 7,130 feet elevation on a 27-percent south-facing slope near Bountiful, Utah. A mature stand of Gambel oak from 8 to 14 feet tall with a basal area of 65 square feet per acre covers the area. A luxuriant herbaceous understory exists beneath the oak.

The soil was developed from mica-schist parent material. The solum is approximately 20 inches deep, below which lies coarse fractured rock.

From 1960 to 1963, annual precipitation was from 25.0 to 32.7 inches. Most of this came during the winters as snow. The summers were warm and dry, but the temperature seldom exceeded 85° F. From the middle of June to the middle of September the area was frost-free.

METHODS

Nine soil moisture access tubes were installed to a depth of 8 feet in each of the three plots, making a total of 27 tubes. From 1962 through 1966, soil moisture readings were taken three times each year (except in 1964 when readings were made only twice) with a Nuclear Chicago[2] soil moisture probe. The measurements were made in May, midsummer, and at the time of maximum soil moisture depletion in the fall.

A survey of the soil and vegetation was made in 1965. Soil samples were collected to a depth of 8 feet and analyzed for texture, organic matter content, and moisture-holding characteristics. The basal area of oak was measured on each plot. In addition, basal area of all stems within a 10-foot radius of each soil moisture access tube was measured, and plotted with respect to distance and direction from the access tube.

---

[2]Mention of trade names does not necessarily imply endorsement by the U.S. Forest Service.

RESULTS

SOIL CHARACTERISTICS

The soil on the plots is coarse-textured with a large portion of the material being greater than 2 mm. in diameter (table 1). Only small amounts of silt, clay, and organic matter are present below the 2-foot depth. Laboratory measurements indicate moisture-holding capacities are considerably greater in the solum, where clay and organic matter are highest, than at lower depths. In contrast, field measurements with the nuclear probe indicated a rather homogeneous moisture-holding capacity of approximately 3.3 inches per foot throughout the entire profile (fig. 1).

SOIL MOISTURE DEPLETION

A distinct pattern of soil moisture depletion was observed. During the early part of the growing season most depletion occurred from the surface 4 feet. As the moisture in the upper soil mantle became less available to plants, greater quantities were removed from the 4- to 8-foot depth (table 2). Although data are shown for only one sampling point, the same trend was observed in all cases.

By the end of each summer, moisture was depleted throughout the entire 8 feet of soil. However, adequate precipitation fell each winter to restore the profile to its maximum storage capacity. No measurable quantity of overland flow occurred, indicating that most of the annual precipitation entered the soil.

The total change in soil moisture during the growing season varied from year to year and from one sampling point to another, although the curves for maximum soil moisture depletion were nearly identical for 3 of the 4 years (fig. 1). In 1962, there was an average change of 12.79 inches in soil moisture. This represented a depletion range of 10.05 to 15.15 inches among the sampling points. In 1963, the average was 12.53 inches with a range from 11.45 to 13.95 inches. In 1965, rainfall was greater during the growing season than in previous years; this resulted in lower soil moisture depletion when a loss of only 6.38 inches of soil moisture was recorded. In 1966, an average soil moisture depletion of 10.73 inches was observed. Although 1966 was an exceptionally dry year, less moisture depletion was recorded than in 1962 and 1963, probably because of early-season evapotranspirational losses before the first measurements were taken.

Table 1.--Properties of the soil at 1-foot depth intervals

(In percent)

Depth (feet)	Gravel[1]	Sand	Silt	Clay	Organic matter	Moisture contents[2] by weight		
						1/3 Atm.	15 Atm.	Avail. H_2O
0-1	27.0	40.4	21.6	11.0	5.19	23.3	12.0	11.3
1-2	41.4	36.2	13.3	9.1	2.11	18.5	9.0	9.5
2-3	73.6	19.8	3.4	3.2	.53	14.1	8.5	5.6
3-4	59.1	35.4	3.5	2.0	.46	11.1	5.9	5.2
4-5	87.1	11.1	1.2	.6	.40	9.2	5.5	3.7
5-6	63.4	30.5	3.6	2.5	.37	11.5	7.6	3.9
6-7	69.3	25.6	2.9	2.2	.29	11.6	8.7	2.9
7-8	75.2	20.8	2.6	1.4	.15	9.3	5.5	3.8

[1] Particles >2 mm. diameter.

[2] Based on particles < 2 mm. diameter.

Table 2.--Soil moisture depletion pattern for a single sampling site during the four growing seasons

Year	Depth interval	Soil moisture depletion		
		May-July	July-September	Total
	Feet	Inches		
1962	0-4	5.78	1.58	7.36
	4-8	2.04	3.38	5.42
1963	0-4	6.75	-.07	6.68
	4-8	3.43	2.03	5.46
1965	0-4	2.97	.06	3.03
	4-8	1.04	2.40	3.44
1966	0-4	4.31	1.21	5.52
	4-8	2.04	2.86	4.90

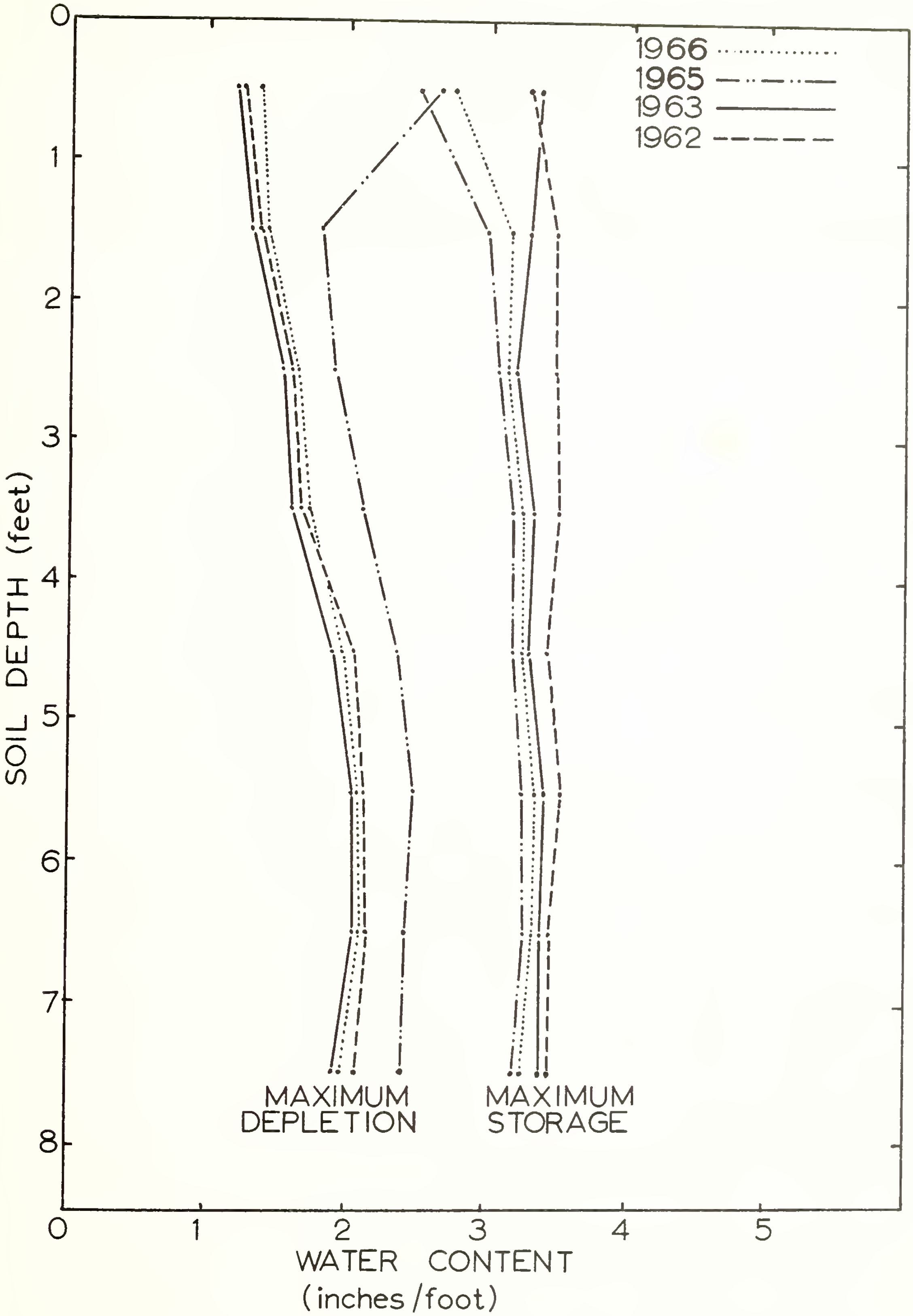


Figure 1.--Moisture contents of soil at 1-foot intervals during four growing seasons.

In an attempt to explain the variability in moisture depletion among sampling points, the number and basal area of oak stems within 10 feet of each access tube were obtained. Considerable variation in the vegetation occurred, but a statistical analysis failed to show a direct relation between tree density or basal area and the amount of moisture depletion. It appears that soil variability and sampling error are more influential on this site than variation in vegetation density. This may not be true on better developed soils, however.

Along with variability encountered in soil moisture depletion, precipitation and evapotranspiration fluctuated considerably from year to year (table 3). Precipitation ranged from 4.08 to 10.68 inches during the growing season. Evapotranspiration varied from 14.81 to 18.80 inches. These values are based on the fact that no surface runoff was recorded during the 4 years of this study. Also, it is assumed that deep percolation losses during the growing season were insignificant.

Table 3.--Precipitation and moisture losses during the four growing seasons

(In inches)

Year	Growing season precipitation	Soil moisture depletion	Evapotranspiration
1962	6.01	12.79	18.80
1963	5.99	12.53	18.52
1965	10.68	6.38	17.06
1966	4.08	10.73	14.81

DISCUSSION

If deep-rooted oak were removed and shallow-rooted grass species planted, much of the soil moisture depletion occurring below the 4-foot level might be eliminated. Without this depletion, less fall and winter precipitation would be required to recharge the soil to its full moisture-holding capacity. This would allow more of the precipitation to go into deep percolation and, at least potentially, permit it to appear as increased streamflow or as ground water.

On the experimental site and on similar sites, the conversion from oak to a shallow-rooted species may contribute an additional 5 to 6 area-inches of water for downstream use during most years through the process described above. On sites having greater soil water-holding capacities, larger evapotranspirational losses might be expected, with subsequently greater soil moisture savings if oak were replaced.

The savings of water realized by replacing oak with a shallow-rooted species would probably be much less during years of high summer precipitation (i.e., 1965). Most of the evapotranspirational loss during these unusually wet growing seasons comes from the surface 4 feet of soil. Whether the surface 4 feet were fully occupied by oak roots or grass roots probably would make little or no difference in the amount or pattern of soil moisture depletion at those times.

AFPS, Ogden, Utah

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-55

1966

HERBICIDES FAIL TO INSURE SUCCESS OF A BRUSHFIELD PRESCRIBED BURN[1]

Russell A. Ryker[2]

ABSTRACT

Seven herbicide spray treatments were compared for their effectiveness in killing brush to prepare a north Idaho brushfield for prescribed burning, and in controlling brush regrowth after the fire. Deadening of the brush did not appear to contribute to success on south- and west-facing slopes, where all plots burned well regardless of the degree of brush kill. On north-facing slopes, the fuel moisture content remained high because of an unusually cool and wet summer, and attempts at burning failed completely even on plots with much dead brush. Brush regrowth on burned areas was not substantially reduced by spraying.

As a result of repeated wildfires and logging practices unfavorable for natural reforestation, brush cover prevails on more than 3/4-million acres of potentially productive forest land in northern Idaho. In reclaiming these acres by artificial reforestation, brush needs to be eliminated or reduced to facilitate planting as well as to reduce competition to newly planted trees. Attempts to remove dense stands of brush by prescribed burning have not always succeeded. Failure occurs most often on north-facing slopes where the brush is usually taller and more dense, and where cool and moist conditions persist longer. On such north-facing slopes, past use of a foliage spray (2,4-D and 2,4,5-T mixture) to kill at least the taller brush and permit faster

---

[1]This administrative study was conducted in cooperation with the Coeur d'Alene National Forest and the Division of Timber Management, Region 1, U.S. Forest Service.

[2]Associate Silviculturist, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah; headquartered at Forestry Sciences Laboratory, Moscow, Idaho, which is maintained in cooperation with the University of Idaho.

drying of the fuel has often been disappointing because of a poor degree of brush kill. To find a treatment that would promise a higher degree of success, several herbicide treatments were tested on a 225-acre brushfield on the Coeur d'Alene National Forest in northern Idaho.

METHODS

The general aspect of the selected site was westerly, but some portions of interior subdrainages faced almost to the north and other portions to the southwest. The slopes were steep, exceeding 60 percent on most of the area. Elevation varied from about 4,400 to 4,900 feet. The brush species present were quite generally represented throughout the area, but the taller-growing species were more prevalent on the lower part of the area and on north-facing slopes.

The area was divided into four plots of approximately 50 acres each; two plots were on the upper slope and two were on the lower. One of each pair was randomly selected for further division into four subplots (using logging roads and topographic features as boundaries); herbicide treatments that included early spraying of the brush in a dormant condition were randomly assigned to these subplots. The other two plots were similarly divided, and three herbicide treatments that involved spraying of the brush in only the leafed-out stage were randomly assigned to three of the four subplots. The unselected subplot in each large plot was eliminated from the study.

Each of the seven treatments was assigned an identifying number and is described as follows:

Treatment no.	Description
1	Dormant spray consisting of 2 lbs. acid equivalent (a.e.) of low-volatil ester of 2,4,5-T and 9-2/3 gallons of No. 2 diesel oil per acre.
2	Treatment #1 plus a later foliage spray consisting of 3 gallons of Tordon 101[3] mixed with 7 gallons of water.
3	Treatment #1 plus a later foliage spray consisting of 1 gallon of Tordon 101 mixed with 9 gallons of water.
4	Treatment #1 plus a later foliage spray consisting of 2 lbs. a.e. of a mixture of 2,4-D and 2,4,5-T (1 lb. a.e. of each), 1 gallon of white diesel, and 8½ gallons of water.
5	Foliage spray consisting of 3 gallons of Tordon 101 and 7 gallons of water.
6	Foliage spray consisting of 1 gallon Tordon 101 and 9 gallons of water.
7	Foliage spray consisting of 2 lbs. a.e. of the mixture of 2,4-D and 2,4,5-T, 1 gallon of white diesel, and 8½ gallons of water.

[3]Dow Chemical Co. registered trademark for a formulation of 4-amino-3,5,6-trichloropicolinic acid ("Tordon," ½ lb./gal.) and 2,4-D (2 lbs./gal.), both as the tri-isopropanolamine salt. The use of the trade name of commercial products is solely for identification and does not imply endorsement by the U.S. Department of Agriculture or the Forest Service.

All herbicide was sprayed by helicopter at the rate of 10 gallons of solution per acre. Dormant spraying was begun as soon as the snow melted in late May. Foliage-spray treatments were begun on June 25, after the leaves had attained three-fourths or more of full development, and were completed on June 29. Temperatures during the June 25-29 period ranged between 40 and 55° F. while spraying was in progress. Relative humidity was approximately 60 percent. Throughout the remainder of that growing season, the weather was unusually cool and wet; and although prescribed burning was planned for mid-August, rainy weather forced postponement until mid-September.

Effects of treatment were measured on four randomly located 1/100-acre circular plots in mid-August of the year of treatment. Estimates were based on the percent of individual shrubs that were outwardly dead. Another examination was made in early October to determine effects of treatment on success of the prescribed burning; these evaluations were based on visually estimated percentages of sample-plot surface that received a satisfactory burn.

Further observations were made during the next growing season. Brush recovery was measured on sample plots that had burned well. On sample plots that had not burned, general observations were made on the recovery or further decline of the brush plants. Douglas-fir trees were planted in May and examined in September to detect effects of possible residual Tordon in the soil. Also, soil samples were collected from each 6-inch layer from the surface to a maximum depth of 36 inches. These were bioassayed by the Dow Chemical Company.

RESULTS

One and a half months after spraying, effectiveness of the herbicides varied with the species of brush (table 1). Taking into consideration the cost of double applications, treatment #6 seemed to be best for most of the species studied here (fig. 1). Treatment #7 gave the least kill. It was about half of that achieved by treatment #1, which in turn was only about half as good as the Tordon treatments #2, #3, #5, and #6.

At the end of the second growing season, observations made on unburned plots that had been sprayed with treatments #4 and #7 showed most species were sprouting both aerially and basally. Regrowth of huckleberry was much reduced, however, on areas that received a dormant spray. On plots receiving foliage treatments of Tordon, huckleberry mortality was light the first year but almost complete by the time of second-year measurements. Snowberry was similarly affected by Tordon but to a lesser degree. The mountain maple, on the other hand, developed some weak basal sprouts during the second year. Myrtleleaf remained substantially unaffected by any of the treatments through the second year.

Combined statistical analyses of data for all species showed that (1) position of brush on the upper or lower slope did not affect the ability of the herbicides to kill the brush, and (2) only treatment #7 (foliage spray of mixed 2,4-D and 2,4,5-T), which was quite ineffective, differed significantly from the others.

Table 1.--Most effective treatment and apparent first-year kill for major brush species

Species	Treatment no.[1]	Percent of kill
Mountain ash (*Sorbus scopulina* Greene)	6	90
Mountain maple (*Acer glabrum* Torr.)	6	[2]80
Huckleberry (*Vaccinium* spp.)	1	80
Snowberry (*Symphoricarpos* spp.)	2	50
Myrtleleaf (*Pachistima myrsinites* (Pursh) Raf.)	None	0
Spiraea (*Spiraea* spp.)	[3]6	93
Rose (*Rosa* spp.)	[3]All	100
Serviceberry (*Amelanchier alnifolia* Nutt.)	[3]6	97
Snowbrush ceanothus (*Ceanothus velutinus* Dougl.)	[3]1	99

[1]Where treatment #6 is listed, treatments 2, 3, and 5 gave comparable results, but are more expensive than 6.

[2]Observations on subsequent studies reveal that this species in other areas has been affected much less by this treatment.

[3]Not all treatments were tested because too few of the plants were present on the sample plots.

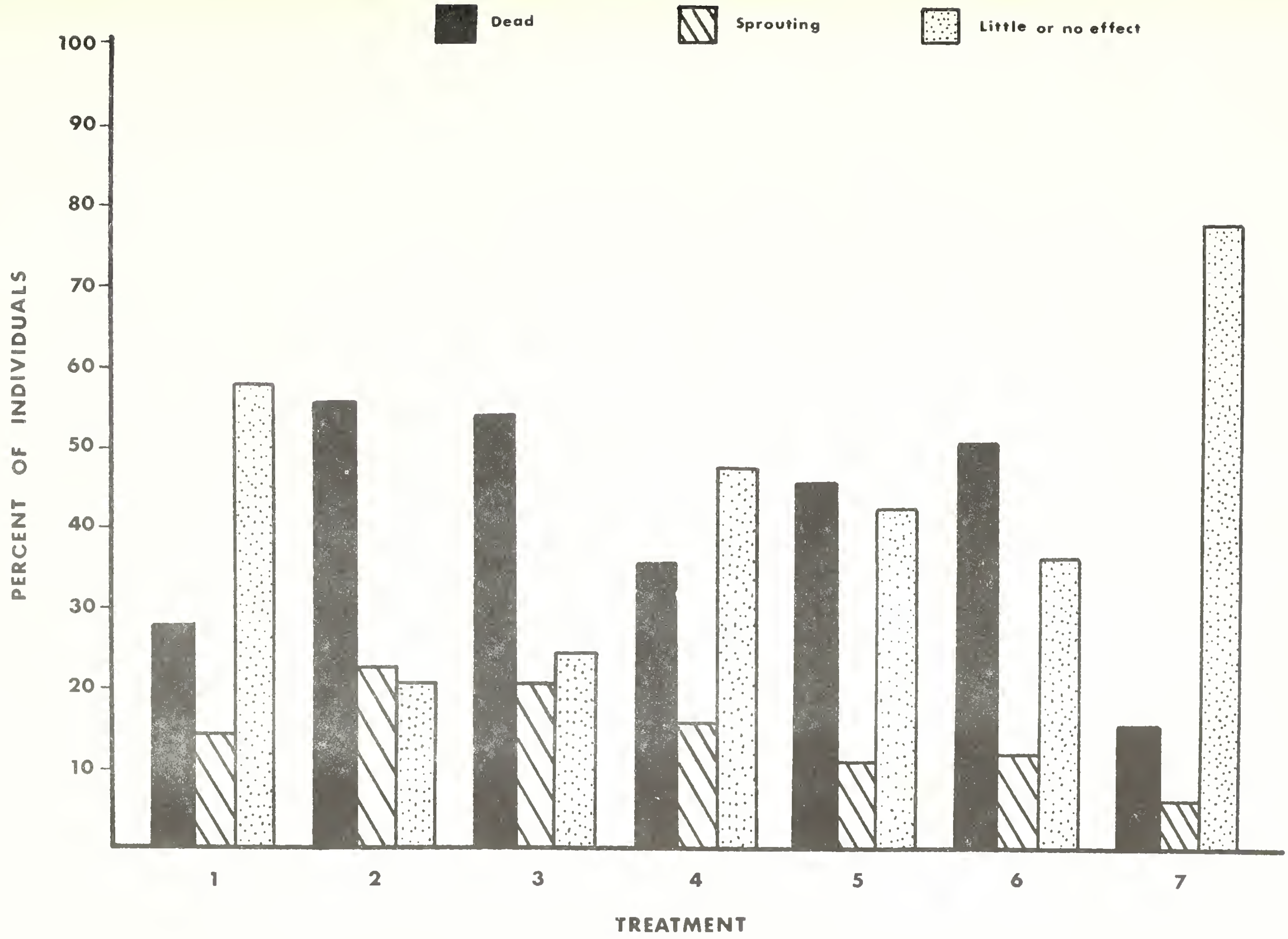


Figure 1. Effectiveness of treatments on all species.

There was no relation between the amount of brush killed by the different herbicide treatments and the percent of surface area that received a complete burn. In fact, the plot with the greatest percent of individual shrubs killed prior to burning had only 15 percent of its surface completely burned, while the plot that had the least amount of brush killed had over 50 percent of its area burned completely. The decisive factor was aspect of the particular location. All north-facing plots burned poorly or not at all. All plots facing to the south or west burned well regardless of the degree of prior brush kill.

Regrowth of brush on the burned plots did not appear to be affected by the herbicide treatment except on the plots receiving treatment 5. Fewer basal sprouts appeared here than on the other treatments (table 2).

The bioassays for residual Tordon in the soil (sensitive to concentrations of less than 0.001 ppm.) indicated no herbicide present for all sampled depths $12\frac{1}{2}$ months after treatment. Also, survival (94-100 percent) and growth (1.6-1.8 inches) of the Douglas-fir planted in the spring of the year following treatment revealed no damaging effects from the herbicide.

Table 2.--Brush regrowth on satisfactorily burned plots at the end of the second season following herbicide treatments

Herbicide	Mean number of stems per 1/100-acre plot		
	Basal sprouts	Stems with aerial sprouts	New seedlings
2,4-D and 2,4,5-T	46	1	16
Tordon 101 (1-gallon rate)	62	0	169
Tordon 101 (3-gallon rate)	24	1	11

DISCUSSION

The main reason for applying herbicides is to reduce brush competition to encourage present or subsequent tree regeneration. But another objective, especially important in brushfield areas, is to kill the brush quickly and thereby produce better fuel conditions for effective burning and clearing of the site prior to planting. This study indicates that the latter goal cannot always be attained on north-facing slopes in northern Idaho, and it seldom may be necessary to try it on south-facing slopes.

On any particular area, the species' composition must be known before an herbicidal treatment can be recommended with any confidence. Identification of treatments that appeared most effective initially on different species (table 1) could be useful in situations where a maximum amount of dead brush material is needed toward the end of the same growing season to improve chances of success in prescribed burning. However, none of the herbicides tested gave much promise of reducing brush regrowth markedly after the burn. Though treatment 5 seemed to inhibit resprouting, results were too limited to justify the cost of this heavy application.

Ceanothus made up the bulk of the new seedlings established on the area in the second year. Their numbers varied greatly from place to place, apparently as a reflection of the amount of Ceanothus seed present before burning rather than as a result of any residual effect of treatments.

The merits of herbicidal sprays as a preparatory measure for prescribed burning must be judged on the basis of specific conditions. If the aspect is generally southerly, chances are good that brush killing prior to the burn is not necessary. If the site is generally northerly and the predominant species are herbicide-susceptible, spraying might well be warranted. However, if weather is not conducive to drying, or if favorable drying conditions are allowed to pass before burning is done, even a spray that kills the brush cannot assure a good burn.

AFPS, Ogden, Utah

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-56

1967

THINNING AND FERTILIZING INCREASE GROWTH IN A WESTERN WHITE PINE SEED PRODUCTION AREA

Russell A. Ryker and Robert D. Pfister[1]

ABSTRACT

Thinning increased diameter growth of 40-year-old western white pine trees by 39 percent. Fertilizing with N and NPK had no effect in unthinned plots, but caused an additional increase of 36 percent in diameter growth in thinned plots. Height growth was not affected by thinning or fertilizing.

Thinning and fertilizer treatments were applied in a vigorous 40-year-old western white pine (Pinus monticola Dougl.) plantation in northern Idaho.[2] The objectives were to determine effects on tree vigor and on seed production.[3] This paper reports the effects on tree vigor in terms of diameter and height growth response only.

[1] Associate Silviculturists, headquartered at Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho, which is maintained in cooperation with the University of Idaho.

[2] This study was established by Burton V. Barnes in the Cathedral Peak Seed Production Area in 1959. The Coeur d'Alene National Forest assisted in the establishment and maintenance of this study. The fertilizer was contributed by Cominco Products, Inc., Spokane, Washington.

[3] Barnes, Burton V. Effects of thinning and fertilizing on production of western white pine seed. J. Forest. (In press.)

METHODS

Two 3-acre blocks were selected for the study. In the fall of 1959, three approximate levels of thinning were established in each block: (1) no thinning (original spacing of 9 X 9 feet), (2) thinned to 20 X 20 feet, and (3) thinned to 30 X 30 feet. Measurements after thinning revealed that the 20- and 30-foot spacings were not achieved.[4] Spacing actually averaged about 22 feet for the 20 X 20 level and about 25 feet for the 30 X 30 level.

Three plots for testing fertilizer were installed within each thinning level in 1960. Plot 1 was not fertilized; the other two plots were each fertilized in 1960, 1961, and 1962 immediately preceding fall precipitation. Plot 2 was fertilized with ammonium nitrate at a rate that provided 300 pounds of elemental nitrogen (N) per acre at each application. Plot 3 was fertilized with a complete (13-13-13) formulation at a rate that provided 312 pounds per acre of elemental nitrogen (N), 136 of phosphorus (P), and 259 of potassium (K) at each application.

Diameter and height were measured on three trees in each plot at the beginning and end of the 4-year period, 1961-1964. To determine if variations occurred from year to year within the 4-year measurement period, annual height increments were measured on two of these trees.

RESULTS

During the 4 years of growth measurement, thinning increased the average annual diameter growth of sample trees by 39 percent (fig. 1). Fertilizing with N or NPK did not affect diameter growth in unthinned plots, but caused an additional increase of 36 percent in growth where thinning had been done. Differences between the two thinning levels and between the two fertilizers were not statistically significant.

Height growth was not stimulated by any of the thinning or fertilizer treatments.

[4] Ibid.

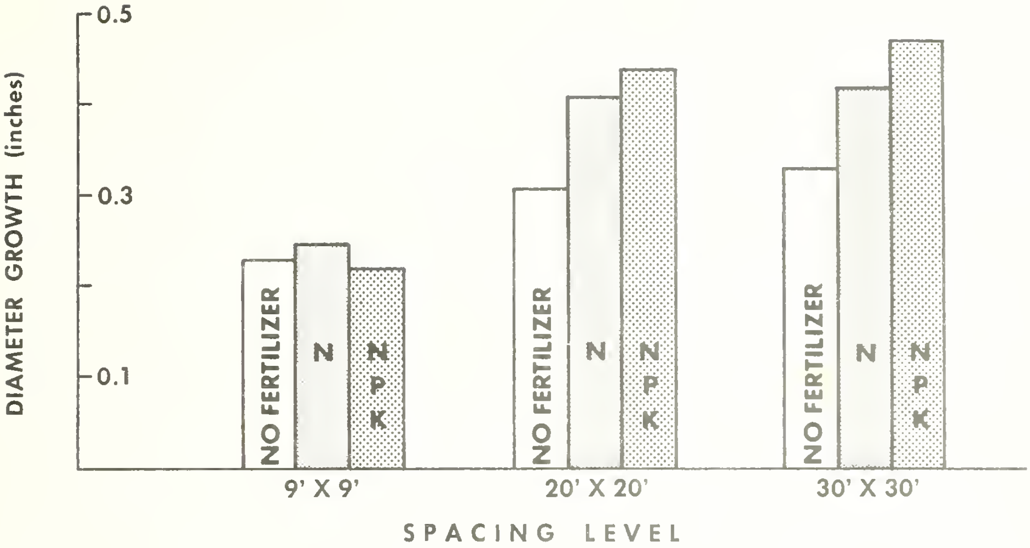


Figure 1.--Mean annual diameter growth of sample trees during the 4-year measurement period.

DISCUSSION

Analyses of soil samples taken from the study area before treatment indicated that levels of N, P, and K were low, so a growth response to fertilization was expected. The substantial increase in diameter growth after fertilization in thinned plots demonstrated that nutrient supply, especially of N, had been below optimum. The addition of P and K did not produce additional growth to the extent anticipated.

Lack of additional response to the wider of the two thinning treatments is to be expected for two reasons. The two levels were actually not very different, and the trees would not be able to utilize the additional growing space beyond 20 X 20 feet until several years after thinning.

The complete lack of growth response to fertilizer within the unthinned plots deserves special comment. It emphasizes that growth is controlled by the "most limiting factor." In the unthinned white pine, this factor was probably soil moisture deficiency due to intense competition. Thinning apparently reduced competition for moisture sufficiently to allow a growth response to fertilization.

Research Note

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

U.S. Forest Service
Research Note INT-57

1967

EARLY PERFORMANCE OF PINUS CONTORTA X BANKSIANA HYBRIDS

James E. Lotan[1]

ABSTRACT

Four Pinus contorta X banksiana hybrids developed in California were planted on two sites in Montana and one site in Idaho to determine whether they were suited to climate and soils of these three test locations and whether they were superior to Montana lodgepole pine. Height, diameter, crown width, number of branches per whorl, vigor, and survival were measured 5 and 10 years following establishment.

Hybrids were well adapted to climate and soils. Most hybrids did not exceed height growth of Montana trees except in Idaho, where Montana trees are not indigenous.

A limited test using Montana and Idaho genotypes for the seed parent showed these genotypes to be superior to California genotypes for developing hybrids for these areas.

Natural interspecific hybrids of lodgepole pine (Pinus contorta Dougl.) and jack pine (Pinus banksiana Lamb.) grow in Alberta, Canada, where the botanical ranges of the two species overlap (Moss 1949). However, few results have been reported on field performance of desirable hybrids of these species. P. contorta X banksiana hybrids were first developed in 1939 when successful pollinations were made in California (Righter and Stockwell 1949; Righter and Duffield 1951). Juvenile height growth of P. contorta X banksiana grown in California equaled or surpassed that of jack pine, which surpasses lodgepole pine in juvenile height growth. Duffield and Snyder (1958) reported that P. contorta X banksiana maintained "hybrid vigor" to 14 years. To combine the faster growth of jack pine and the straighter stem and smaller limbs of lodgepole pine, the Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station, developed F_1 lodgepole pine X jack pine hybrids. These hybrids were field-tested at two locations in Montana and one location in northern Idaho.[2] This paper presents results at 10 years after test planting the California-developed hybrids, together with results at 5 years after test planting indigenous lodgepole pine seed parents.

The objectives of the study were to determine whether F_1 hybrids developed in California were (1) suited to the climate and soils of the three test locations, and (2) superior to indigenous lodgepole pine.

[1]Research Forester, headquartered at Forestry Sciences Laboratory, Bozeman, Montana, which is maintained in cooperation with Montana State University.

[2]Cooperating in this field test were: (1) Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station, (2) School of Forestry, University of Montana, and (3) Lewis and Clark National Forest.

The study was installed by A. E. Squillace, formerly with Intermountain Forest and Range Experiment Station, now with Southeastern Forest Experiment Station.

TESTING PROCEDURES

HYBRIDS DEVELOPED IN CALIFORNIA

The hybrids developed in California were planted at each of the following three locations.

Lewis and Clark National Forest.--These test plots are located near White Sulphur Springs, Montana, on the Adams Creek drainage at an elevation of 6,400 feet. The area was clearcut in 1948 and broadcast-burned in September 1949. The soil is a deep clay on a gentle (less than 5 percent) southwest slope.

Lubrecht Experimental Forest.--This property, owned by the State of Montana, is administered by the University of Montana. It is 24 miles east of Bonner, Montana, on the Blackfoot Highway, at an elevation of 4,100 feet. The area was clearcut in 1934, and prior to planting in 1950 it had supported a few scattered lodgepole pine and ponderosa pine saplings. The soil is a deep, rocky, very fine, sandy loam on a moderate (5 to 15 percent) northeast slope.

Priest River Experimental Forest.--Plots in this Forest are on Federal land near Priest River, Idaho, and are administered by the Intermountain Forest and Range Experiment Station. They are located along the Gisborne Mountain Lookout Road at an elevation of 2,400 feet. Prior to planting, the area supported a stand of 80-year-old larch and white pine. The soil is a light brown, very fine, sandy loam, 14 to 18 inches deep, underlain with rocky clay subsoil on a 25-percent northwest slope.

Seedlings were planted at each location in 1950 and 1952. Parentage of the seedlings was as follows:

Seed parent	Pollen parent
1950 test:	
P. contorta (Calif.)	P. banksiana (Wisc.)
P. contorta (Calif.)	Wind
P. contorta (Mont., Gallatin N.F.)	Wind
P. contorta (Mont., Lolo N.F.)	Wind
P. banksiana (Minn.)	Wind
1952 test:	
P. contorta (Calif., Eld-8-1,[3] 7,300 ft. elev.)	P. banksiana mix[4]
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	P. banksiana mix
F_1 P. contorta X P. banksiana (Calif., 5,700 ft. elev.)[5]	Wind
P. contorta (Calif., Eld-9-1, 7,100 ft. elev.)	Wind
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	Wind
P. contorta (Mont., Deerlodge N.F.)	Wind
P. contorta (Mont., Lewis & Clark N.F.)	Wind
P. banksiana (Minn.)	Wind

With the exception of Minnesota jack pine planted in 1952, all seedlings were grown in the Savenac Nursery in northwestern Montana. The seed from hybrids and nonindigenous sources were supplied to the Savenac Nursery by the Institute of Forest Genetics. The Minnesota jack pine planted in 1952 was grown at the Evaleth Nursery near Duluth, Minnesota.

At each planting site, five 2-year-old seedlings (1-1 stock except Evaleth seedlings, which were 2-0 stock) were planted in a completely randomized design, spaced 5 X 5 feet apart in each of two blocks.

---

[3]Symbol refers to Eldorado County, California, and numbers assigned to plots and to seed parent trees by the Institute of Forest Genetics, California.

[4]Exact source of pollen is unknown; it is probably P. banksiana growing at the Institute of Forest Genetics Arboretum, California.

[5]This seed was collected from hybrid trees growing at the Institute of Forest Genetics, California.

The few seedlings that failed during the first 2 years were replaced by seedlings from comparable lots that had been planted nearby at the same time as the initial planting. All plots were protected by a deerproof fence.

Survival was recorded and height growth was measured in the fall following establishment. The following measurements were taken 5 and 10 years following establishment:

1. Total height (feet).
2. Diameter (inches) outside bark at the root collar.
3. Crown width (feet).
4. Number of branches in current whorl.
5. Vigor.

HYBRIDS DEVELOPED IN MONTANA AND IDAHO

To produce a lodgepole pine X jack pine hybrid using local lodgepole pine seed trees,[6] controlled pollinations were made in 1951 on two lodgepole pine trees near Deer Creek, Lolo National Forest, Montana, and on two lodgepole pine trees near Clarkia, Idaho. The Pacific Southwest Forest and Range Experiment Station supplied jack pine pollen from two trees in the Institute of Forest Genetics Arboretum. Seed produced from these pollinations were collected in 1952 and sown at the Savenac Nursery in May 1953, as indicated below:

Seed parent	Pollen parent
P. contorta$_1$ (Mont., Lolo N.F.)	P. banksiana mix[7]
P. contorta$_1$ (Mont., Lolo N.F.)	Wind
P. contorta$_2$ (Mont., Lolo N.F.)	P. banksiana mix
P. contorta$_1$ (Idaho, St. Joe N.F.)	P. banksiana mix
P. contorta$_1$ (Idaho, St. Joe N.F.)	Wind
P. contorta$_2$ (Idaho, St. Joe N.F.)	P. banksiana mix
P. contorta mix[8] (Mont., Missoula County)	Wind
P. contorta mix (Idaho, St. Joe N.F.)	Wind

In addition, seed from wind-pollinated parent trees and from mixed seed parent trees on the St. Joe National Forest and the Lubrecht Experimental Forest were collected in 1952 and planted at the Savenac Nursery on the same date as the hybrids. The seedlings were transplanted the following spring and were outplanted in the spring of 1955 as 1-1 stock.

A randomized block design, replicated twice, was used on the Lubrecht Experimental Forest and on the Priest River Experimental Forest. Within each block, six of the eight lots were represented by five seedlings planted in rows at a spacing of 5 X 5 feet. Unfortunately, there were not enough seedlings to complete the experimental design. The hybrid P. contorta$_1$ (Mont.) X banksiana was not planted at Priest River where P. contorta$_1$ (Mont.) X wind seedlings were planted. P. contorta$_1$ (Idaho) X wind seedlings were not planted at Lubrecht where P. contorta$_1$ (Idaho) X banksiana trees were planted. At both the Lubrecht and Priest River Experimental Forests, two additional hybrids were planted: P. contorta$_2$ (Idaho) X banksiana (at Priest River) and P. contorta$_2$ (Mont.) X banksiana (at Lubrecht).

At the end of the first, third, and fifth growing seasons, trees were measured as described above for the other test plantings.

[6]This phase of the study was started by A. E. Squillace, Principal Plant Geneticist, and established by David Tackle, Research Forester, now with Pacific Northwest Forest and Range Experiment Station.

[7]Pollen was supplied by Institute of Forest Genetics, California, and was taken from two P. banksiana designated "V14" and "V21."

[8]Seed collected from several trees.

RESULTS

CALIFORNIA HYBRIDS

1950 Test Plantings

Height growth of the California hybrid at the end of 10 years did not significantly exceed height growth of Montana lodgepole pine in the 1950 test (table 1) except at Priest River, where the hybrid was significantly taller than the Gallatin lodgepole pine. Seedlings from all lots grew faster at the Lubrecht site, but growth of the California hybrid did not differ significantly from that of the native lodgepole pine.

Jack pine usually grew significantly taller than the indigenous pines in this test; but at Lewis and Clark it did no better than indigenous trees. California lodgepole pine grew consistently slower than any other lot at all locations. Because many of the data for diameter growth of the 1950 test were missing, the data remaining were not analyzed statistically. However, average diameter growth outside bark at the root collar is presented in table 1.

In the 1950 test, both the hybrid and jack pine had grown wider crowns than Montana trees; but the Montana trees, in turn, were wider than California trees.

Trees did not vary significantly among lots in number of branches per whorl.

Trees from all lots survived well, but indigenous trees had the best survival rate. There was little variation in vigor among lots, but California lodgepole pine was rated less vigorous than other lots.

Table 1.--Average height and diameter by seed lot and study area, 1950 test plantings

TOTAL HEIGHT

Seed parent	Pollen parent	Study area: Lewis & Clark N.F.	Study area: Priest River	Study area: Lubrecht Forest
		- - - - - -	Feet	- - - - - -
P. contorta (Calif.)	Wind	2.63	2.65	4.10
P. contorta (Mont., Gallatin N.F.)	Wind	5.47	4.67	8.58
P. contorta (Mont., Lolo N.F.)	Wind	[1]4.39	6.49	8.46
P. contorta (Calif.)	P. banksiana (Wisc.)	3.80	6.86	9.01
P. banksiana (Minn.)	Wind	4.26	9.95	10.44

DIAMETER[2] (outside bark at root collar)

Seed parent	Pollen parent	Lewis & Clark N.F.	Priest River	Lubrecht Forest
		- - - - - -	Inches	- - - - - -
P. contorta (Calif.)	Wind	1.43	0.84	1.76
P. contorta (Mont., Gallatin N.F.)	Wind	1.07	1.06	2.43
P. contorta (Mont., Lolo N.F.)	Wind	1.02	1.04	2.11
P. contorta (Calif.)	P. banksiana (Wisc.)	0.90	0.95	2.48
P. banksiana (Minn.)	Wind	0.65	1.20	2.28

[1]Any two means not having a common line are statistically significant at the 95-percent level of probability when compared by Kramer's adaptation of Duncan's multiple range test (Kramer 1956).
[2]Diameter data were not analyzed because considerable pertinent data were missing.

1952 Test Plantings

Hybrids in the 1952 plantings were tallest at Priest River; both hybrids were significantly taller there than at either of the Montana lodgepole pine lots (table 2). At the Lubrecht site the hybrid *P. contorta* (Eld-8-1 Calif., 7,300 ft.) X *banksiana* grew significantly taller than the Deerlodge National Forest lodgepole pine, but neither hybrid was significantly taller than the lodgepole pine from Lewis and Clark National Forest. At the Lewis and Clark site the higher elevation hybrid was significantly taller than the Deerlodge trees, but was not taller than the Lewis and Clark trees. Hybrids from the lower elevation were no taller than the Deerlodge lodgepole pine and were significantly shorter than the Lewis and Clark pine. At all locations, California lodgepole pine grew consistently slower than any other lot.

As in the 1950 plantings, jack pine grew significantly taller than the indigenous pines except at Lewis and Clark, where most of the lot failed to survive. At all locations jack pine trees were serpentine and bent.

Admittedly, 10-year results are somewhat premature for analysis of diameter growth of the hybrids, but, for the record, diameters at the root collar are listed in table 2.

Seedlings from the two hybrids, jack pine, and Lewis and Clark lodgepole pine all had significantly wider crowns than Deerlodge trees, but did not differ significantly from each other. The California trees and the hybrid X wind had narrower crowns than all other lots.

The number of branches per whorl did not differ significantly.

All lots survived well except jack pine at Lewis and Clark National Forest. Investigators rated vigor of the hybrids no differently from vigor of either Montana trees or California lodgepole pine.

MONTANA HYBRIDS

Not enough seedlings were available to complete the experimental design on the Montana hybrids. Only four out of eight lots could be analyzed statistically. The four lots not analyzed statistically are included in table 3 for comparison.

Hybrids developed in Montana were taller at 5 years than Montana lodgepole pines at the Lubrecht site. Although measurements of hybrids from the Montana seed parents were not analyzed, the hybrids were taller than the Idaho hybrids, which were significantly taller than Montana trees. At Priest River, the Idaho hybrids included in the analysis did not grow significantly taller than the Lolo pines, but were taller than pines from Missoula County. Unfortunately, the two hybrids that grew tallest at the Lubrecht site were not represented at Priest River.

Table 2.--Average height and diameter by seed lots and study area, 1952 test plantings

TOTAL HEIGHT

Seed parent	Pollen parent	Study area: Lewis & Clark N.F.	Study area: Priest River	Study area: Lubrecht Forest
		- - - - - - -	-Feet-	- - - - - - -
P. contorta (Calif., Eld-9-1, 7,100 ft. elev.)[1]	Wind	[2]2.06	2.03	2.84
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	Wind	1.83	2.14	3.11
F_1 P. contorta X banksiana[3] (Calif., 5,700 ft. elev.)	Wind	3.25	4.71	3.56
P. contorta (Mont., (Deerlodge N.F.)	Wind	4.23	3.32	5.96
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	[4]P. banksiana mix	3.94	7.47	6.55
P. contorta (Mont., Lewis & Clark N.F.)	Wind	5.19	3.97	6.77
P. contorta (Calif., Eld-8-1, 7,300 ft. elev.)	P. banksiana mix	5.40	8.38	6.48
P. banksiana (Minn.)	Wind	[5]1.40	8.00	8.28

DIAMETER (outside bark at root collar)

Seed parent	Pollen parent	Lewis & Clark N.F.	Priest River	Lubrecht Forest
		- - - - - - -	-Inches-	- - - - - - -
P. contorta (Calif., Eld-9-1, 7,100 ft. elev.)	Wind	1.00	0.66	1.16
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	Wind	0.77	0.73	1.36
F_1 P. contorta X banksiana (Calif., 5,700 ft. elev.)	Wind	0.80	0.80	0.81
P. contorta (Mont., Deerlodge N.F.)	Wind	1.24	0.75	1.72
P. contorta (Calif., Eld-10-1, 6,500 ft. elev.)	P. banksiana mix	1.10	1.53	1.87
P. contorta (Mont., Lewis & Clark N.F.)	Wind	1.39	0.82	2.21
P. contorta (Calif., Eld-8-1, 7,300 ft. elev.)	P. banksiana mix	1.53	1.73	1.80
P. banksiana (Minn.)	Wind	0.20	1.28	1.68

[1]Symbol refers to Eldorado County, California, and to numbers assigned to plots and seed parent trees by the Institute of Forest Genetics, California.

[2]Any two means not having a common bracket are statistically significant at the 95-percent level of probability when compared by Kramer's adaptation of Duncan's multiple range test (Kramer 1956).

[3]This seed was collected from hybrid trees growing at the Institute of Forest Genetics, California.

[4]Exact source of pollen unknown; probably P. banksiana growing at the Institute of Forest Genetics, California.

[5]Not a significant value; only one tree survived.

Table 3.--Average height by seed lots and study areas, Montana-Idaho hybrids test plantings (1955)

TOTAL HEIGHT

Seed parent	Pollen parent	Study area: Priest River	Study area: Lubrecht Forest
		- - - - - - - -Feet- - - - - -	
Lots analyzed:			
P. contorta mix[1] (Mont., Missoula Co.)	Wind	2.39	[2]2.05
P. contorta$_1$ (Mont., Lolo N.F.)	Wind	3.95	2.13
P. contorta$_1$ (Idaho, St. Joe N.F.)	[3]*P. banksiana* mix (Calif.)	3.37	2.34
P. contorta mix (Idaho, St. Joe N.F.)	Wind	3.70	2.43
Lots not analyzed:			
P. contorta$_2$ (Mont., Lolo N.F.)	*P. banksiana* mix (Calif.)	**	2.70
P. contorta$_1$ (Mont., Lolo N.F.)	*P. banksiana* mix (Calif.)	**	2.93
P. contorta$_1$ (Idaho, St. Joe N.F.)	Wind	4.02	**
P. contorta$_2$ (Idaho, St. Joe N.F.)	*P. banksiana* mix (Calif.)	4.22	**

[1] Seed collected from several trees.

[2] Any two means not having a common bracket are statistically significant at the 95-percent level of probability.

[3] Pollen was received from the Institute of Forest Genetics, California, and was taken from two *P. banksiana* trees designated "V14" and "V21."

**Missing lots.

DISCUSSION AND CONCLUSIONS

The wide differences between Montana lodgepole pine and California lodgepole pine shown by this study indicate great variation in height and diameter growth within species. Except for number of branches per whorl and vigor classification, Montana lodgepole pine performed significantly better than California lodgepole pine. Obviously, combining these particular California genotypes with jack pine did not provide the best genetic composition for superior performance at the two Montana locations.

For these reasons, the pollination project using Montana lodgepole pine seed trees was begun in 1951. Unfortunately, the test of the Montana-developed hybrid was not complete enough to provide a basis for sound comparisons, but it suggested that local trees are superior to California trees for developing hybrids for use in Montana and Idaho.

Generally, the hybrids were adequately suited to the climate and soils of the three locations but did not prove superior to Montana lodgepole pine. After 10 years from planting, most hybrids failed to show much advantage in the traits measured. The hybrids test-planted at Priest River were an exception to this. Most of them performed significantly better than Montana lodgepole pine in height growth, and possibly in diameter growth and crown width. However, at Priest River the Montana trees, themselves, were not indigenous.

The existence of geographic variation and elevational clines in lodgepole pine is well known (Critchfield 1957). Thus, lodgepole pine represents a vast reservoir of genotypes that may be reflected in a variety of responses of developed hybrids at different locations. As shown in this study, a strong interaction of genotype and environment exists between a particular taxon and location of planting. In lodgepole pine, hybrids would need to be developed for a variety of sites. Long-term, careful, and extensive testing using indigenous genotypes for seed parents apparently is needed to develop hybrids superior to indigenous lodgepole pine.

LITERATURE CITED

Critchfield, W. B.
1957. Geographic variation in *Pinus contorta*. Maria Moors Cabot Found. Pub. 3, 118 pp., illus.

Duffield, J. W., and E. B. Snyder.
1958. Benefits from hybridizing American forest tree species. J. Forest. 56: 809-815, illus.

Kramer, C. Y.
1956. Extension of multiple range tests to group means with unequal number of replications. Biometrics 12: 307-310.

Moss, E. H.
1949. Natural pine hybrids in Alberta, Canada. Can. J. Res. 27(5): 218-229, illus.

Righter, F. I., and J. W. Duffield.
1951. Interspecific hybrids in pines. J. Hered. 42: 75-80, illus.

Righter, F. I., and P. Stockwell.
1949. The fertile species hybrid, *Pinus murray banksiana*. Madroño 10: 65-69, illus.

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-58

1967

MATURITY INDICES FOR GRAND FIR CONES

Robert D. Pfister[1]

ABSTRACT

Cones collected at 10-day intervals were used to evaluate possible indices of cone maturity. Although both specific gravity and moisture content decreased with maturity, specific gravity was the better indicator of the actual stage of maturity. Adherence of seed to cone scales and color of seed wings also appeared promising as qualitative indices.

Improvement of grand fir (*Abies grandis* (Dougl.) Lindl.) seed quality is needed for successful and economical reforestation programs. Past regeneration efforts have been hampered by poor seed quality that has been attributed to several causes, including premature cone collection, improper storage of cones and seed, and injury to seed during cleaning. Premature cone collection is probably the most important single factor for grand fir because collectors have not had adequate guidelines for determining maturity in the field.

Past studies have shown that seed can be extracted more economically from mature cones and has a higher germinability than seed from immature cones (18). It has also been demonstrated that completely mature seed retains its viability during storage better than immature seed does (7, 23). Thus, agencies involved with tree seed collection need a reliable index for determining cone maturity. Such an index must be not only objective and applicable in the field, but should also be definitive to the extent of indicating the degree of maturity.

---

[1]Research Forester, headquartered at Forestry Sciences Laboratory, Moscow, Idaho, which is maintained in cooperation with the University of Idaho. The author wishes to thank Dr. Te May Ching, Oregon State University, for making available the facilities of the University's seed research laboratory, and Dr. J. H. Rediske, Weyerhaeuser Timber Company, for supplying a copy of his manuscript on seed maturity in noble fir.

Specific gravity of cones has been tested more widely than any other index as a means to assess cone maturity (2, 3, 4, 7, 8, 9, 10, 13, 14, 19, 20, 22, 23). This measure has proved quite reliable for most species. For species where specific gravity is poorly related to seed maturity, other criteria may be needed.

Many other techniques have been used to evaluate maturity. Moisture content has been related to cone maturity for grand fir, Douglas-fir, and Colorado spruce (1, 2, 3). Qualitative characteristics that have also been tested as indices of maturity include: cone color (5, 8, 10, 13, 19, 22), cone firmness (5), and seed color and firmness (5, 22). One study showed that time of cutting by squirrels was related to cone maturity in Douglas-fir (12). The usefulness of this relationship is questionable because, as Maki (13) states, squirrels are chiefly interested in the carbohydrates of the endosperm--not in the germinative energy of the embryo.

The increasing demand for grand fir seed for reforestation has magnified the problem of obtaining mature, viable seed. When 1961 proved to be a good year for grand fir seed production in northern Idaho, we capitalized on this as an opportunity to begin a study of possible maturity indices. The work was done in conjunction with another study involving artificial cone-ripening techniques (15).

METHODS

Cones were collected from grand fir trees in a mature, mixed conifer stand in the Deception Creek area of the Coeur d'Alene National Forest. The stand is on a northerly slope at about 3,200 feet elevation within a habitat that is ecologically characterized as *Thuja-Tsuga/Pachistima* (6). Cones were collected six times at 10-day intervals from July 25 to September 13, 1961, by felling two or three trees on each collection date. The cones were covered with damp muslin to prevent desiccation during transport to the Deception Creek Experimental Forest headquarters.

Immediately after each collection, observations were recorded on cone color and firmness, seed color and firmness, and seed wing color. Twenty sound cones were also selected, weighed, immersed in water in a graduate cylinder to determine volume, and ovendried at 105° C. until constant dry weight was obtained. Specific gravity and moisture content were computed from these values.

An additional 20 sound cones from each collection date were placed on racks in an open shed to dry before seed extraction. These cones were separated into two replicates containing 10 cones each.

On October 25, after 6 to 12 weeks of cone storage (depending on the particular collection date), seeds were extracted, screened to remove the scales, hand-rubbed to remove the seed wings, and cleaned with a small fan. Cleaning did not remove the empty seeds. The cleaned seed was then stored at about 1° C. for approximately 1 month. Six 100-seed samples of the cleaned seed from each collection date were then stratified between layers of damp peat moss at about 1° C. for 26 days prior to the germination tests.

Evaluation of seed weight and germination tests began in early January.[2] Fresh weight was determined for two 100-seed samples of stratified and unstratified seed from each collection date. Dry weight and moisture content were determined for one 100-seed sample of unstratified seed from each collection date.

[2]All seed weight and germination tests were conducted in the seed physiology laboratory at Oregon State University.

Germination tests were conducted on six 100-seed samples of stratified and two 100-seed samples of unstratified seed from each collection date using plastic petri dishes containing "Sponge Rok."[3] Alternating temperatures of 20° C. (16 hours daily in the dark) and 30° C. (8 hours daily with light) were maintained during these tests. Germination counts were made at 2- or 3-day intervals for 30 days. Ungerminated seeds were cut to determine whether they were filled, empty, or woody. If seeds were filled, tetrazolium chloride was used to establish apparent viability.

Ten seedlings, approximately 5 days old, were selected to represent each sample of stratified seed. Length of each seedling was measured, and each 10-seedling group was weighed to provide means for comparing early vigor.

RESULTS

Seed maturity increased as collection dates approached the time of natural seed fall (table 1). Germinative capacity[4] and seed dry weight increased, while seed moisture content decreased--during the period up to and including the final collection--when cones were beginning to shed their seed naturally. Unstratified seeds from the August 15 collection germinated very slowly, but the rate of germination for later collections was uniformly rapid. Date of collection did not affect seedling vigor as measured by total length. The increase in seedling weight probably reflects normal seed weight trends.

Table 1.--Measures of seed maturity and resulting seedling vigor by cone collection dates

Collection date[1]	Seed maturity				Seedling vigor	
	Germinative capacity	Dry weight	Moisture content	Rate of germination[2]	Length	Weight
	Percent	Gms./100 seeds	Percent	Days	Mm.	Gms./10 seedlings
August 4	0.0	[3]1.35	11.4	--	--	--
August 15	30.3	1.74	9.0	24.1	35.6	0.690
August 24	29.4	1.71	9.6	9.0	40.3	.778
September 3	53.8	2.56	8.3	11.0	39.7	.902
September 13	71.2	2.67	7.2	11.4	38.3	.959

[1]Seeds from the July 25 collection shriveled during storage and were not extracted.
[2]Number of days required for germination of nonstratified seed to reach 50 percent of germinative capacity.
[3]Any means connected by brackets are not significantly different ($P < 0.05$) by Duncan's Multiple Range Test.

[3]Material produced by Paramount Perlite Co., Paramount, California. Trade names given here are for purposes of identification only and do not constitute an endorsement by the U.S. Forest Service.

[4]Includes those seeds that actually germinated plus the seeds that the tetrazolium test indicated were viable. The latter usually amounted to less than 2 percent.

Cone specific gravity and moisture content decreased with later collection dates (table 2). After August 4, the decrease in specific gravity was quite uniform and reached an observed low of 0.88 on September 3. Change in average moisture content was small (13 percent) during the observed period but showed a definite downward trend, although considerable variation was present. Cones were breaking up on the last collection date, September 13, so no cone measurements could be made. Sufficient data were not available to determine the degree of correlation between specific gravity and germination.

Seed wing color and degree of seed attachment seem to be the most promising qualitative indicators of maturity. Seed wing color progressed from green to purple, and became brown prior to the last two collections (table 2). When cones were broken apart for examination on September 3, the seed fell away from the scales. Prior to this date, seeds were attached firmly to the cone scales. These two changes were first observed in the September 3 collection and they correspond with the relatively high germinative capacity of seed collected on that date.

Cones were firm and of dark green color until the September 3 collection, at which time they had some brown-tipped scales and were easily compressed when squeezed by hand. However, maggot-infested cones exhibited the same characteristics prior to their disintegration about August 24. Seeds were milky in the early collections and firm in the last three collections. Color of seeds did not differ appreciably after the second collection date. Cotyledons had differentiated to the point at which they were readily distinguishable by the September 3 collection.

DISCUSSION

Total number of seeds was used as the basis for calculating germinative capacity because the proportion of empty, woody, and filled seeds varied with collection date. Many seeds from the early collections, apparently normal at time of collection, shriveled before the germination tests were run. Also, there was no clear distinction between woody seeds and empty seeds.

Germinability of grand fir seed improved until the time of seed dispersal. This behavior differed somewhat from the usual pattern of coniferous seed maturity wherein germinability increases rapidly in early collections and then levels off prior to seed dispersal.

Table 2.--Comparison of seed maturity with cone characteristics and seed wing color

Collection date	Germinative capacity	Cone specific gravity	Cone moisture content	Seed wing color
	Percent		Percent of fresh wt.	
July 25	[1] --	[2] 1.00	74.2	Green with purple tip
August 4	0.0	1.02	67.3	All purple
August 15	30.3	1.00	64.5	All purple
August 24	29.4	0.96	64.7	All purple
September 3	53.8	0.88	61.2	Mostly brown
September 13	71.2	--	--	Brown

[1] Seeds from the July 25 collection shriveled during storage and were not extracted.
[2] Any means connected by brackets are not significantly different ($P < 0.05$) by Duncan's Multiple Range Test.

The germinative capacity of seed from the August 24 collection was much lower than expected. Low specific gravity and rapid rate of germination indicated that the cones were quite close to maturity; this was further indicated by lack of response to artificial cone-ripening treatments (15). Some of the trees selected for collection on that date may have been ineffectively pollinated or inherently poor quality seed producers. An unexplained similar depression in the germination curve for noble fir seed (10) collected repeatedly from the same trees indicates that other factors may also be responsible.

Average moisture content and average specific gravity of cones both followed the expected pattern of decrease with time, but are not strictly related. Moisture content of cones varied greatly among trees. Because of this variation and the small amount of change during the period studied, cone moisture content appears less reliable than specific gravity as a quantitative index of maturity. Moreover, specific gravity is preferred as an index because it is easier to determine.

Cone color and cone firmness both indicated maturity. All immature cones in the study area were green, but in some areas color of immature cones reportedly varies from yellowish green to purplish (11). Color and firmness are difficult to define or measure. Also, insect-infested cones may discolor and lose firmness prior to maturity. Thus, these two qualitative criteria could easily lead inexperienced cone collectors to erroneous determinations of maturity.

Seed color darkened by the second collection date and seeds became firm by the third collection. However, both of these measures lack the precision necessary to define maturity adequately.

Changes in color of seed wings appeared to be directly related to seed maturity. However, color differences were observed for the green variety of cones only, so further testing should be done before this relationship can be recommended as a sole guide to seed maturity.

A logical and simple maturation test was provided where seeds fell away from the cone scales when the cones were broken apart. Although the time remaining for collection may be less than 10 days, the seed should be near the maximum possible germinative capacity.

RECOMMENDATIONS

As a result of this study the following recommendations are made for collecting grand fir cones to obtain high quality seed:

1. Cones should not be collected until their average specific gravity is less than 0.90.[5]
2. Cones may be collected when seeds are no longer attached firmly to the scales.
3. In areas where immature cones are green, cones may be collected when the seed wing color changes from purple to brown.

Additional study to provide a more critical index of degree of seed maturity would be desirable. Embryo development, including cotyledon differentiation as observed in this study and embryo elongation as reported for Douglas-fir (2, 8) is worthy of exploration. Length of cone storage should also be considered in future maturity studies since its effect has been demonstrated for noble fir (16) and Douglas-fir (17).

[5] A container of olive oil (or a half-and-half mixture of S.A.E. 20 motor oil and linseed oil) may be carried in the field. Mature cones (specific gravity < 0.90) will float and immature cones will sink. Sound cones from several trees in each collection area should be tested.

LITERATURE CITED

1. Ching, Te May.
   1960. Seed production from individual cones of grand fir (Abies grandis Lindl.) J. Forest. 58: 959-961.

2. Ching, Te May, and Kim K. Ching.
   1962. Physical and physiological changes in maturing Douglas-fir cones and seed. Forest Sci. 8: 21-31.

3. Cram, W. H.
   1956. Maturity of Colorado spruce cones. Forest Sci. 2: 26-30.

4. Cram, W. H., and H. A. Worden.
   1957. Maturity of white spruce cones and seeds. Forest Sci. 3: 263-269.

5. Crossley, D. I.
   1953. Seed maturity in white spruce. Canada Dep. of Resources and Develop., Forest. Br., Silvicult. Res. Note 104, 16 pp.

6. Daubenmire, R.
   1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecol. Monogr. 22: 301-330.

7. Eliason, E. J., and Joseph Hill.
   1954. Specific gravity as a test of ripeness with red pine. U.S. Dep. Agr., Forest Serv. Tree Planters' Notes 17: 1-4.

8. Finnis, J. M.
   1950. Seed maturity in Douglas-fir. British Columbia Forest Serv. Res. Note 18, 8 pp.

9. Fowells, H. A.
   1949. An index of ripeness for sugar pine seed. U.S. Forest Serv., Calif. Forest and Range Exp. Sta. Res. Note 64, 5 pp.

10. Franklin, Jerry F.
    1965. An exploratory study of cone maturity in noble fir. U.S. Forest Serv. Pacific Northwest Forest and Range Exp. Sta. Res. Note 21, 12 pp.

11. Harlow, William M., and Ellwood S. Harrar.
    1941. Textbook of dendrology. 2d ed. New York and London: McGraw-Hill, 542 pp.

12. Lavender, Dennis P., and Wilbur H. Engstrom.
    1956. Viability of seeds from squirrel-cut Douglas-fir cones. Oregon State Board of Forest. Res. Note 27, 19 pp.

13. Maki, T. E.
    1940. Significance and applicability of seed maturity indices for ponderosa pine. J. Forest. 38: 55-60.

14. McLemore, B. F.
1959. Cone maturity affects germination of longleaf pine seed. J. Forest. 57: 649-650.

15. Pfister, Robert D.
1966. Artificial ripening of grand fir cones. Northwest Sci. 40: 103-112.

16. Rediske, J. H.
1961. Maturation of Douglas-fir seed--a biochemical study. Forest Sci. 7: 204-213.

17. Rediske, J. H., and David C. Nicholson.
1965. Maturation of noble fir seed--a biochemical study. Weyerhaeuser Co., Centralia, Wash., Weyer. Forest. Pap. 2, 15 pp.

18. Roe, Eugene I.
1960. August-collected cones yield poor red pine seed. U.S. Forest Serv. Lake States Forest Exp. Sta. Tech. Note 170, 1 p.

19. Rudolf, Paul O.
1940. When are pine cones ripe? Minnesota Acad. Sci. Proc. 8: 31-38.

20. Schubert, Gilbert H.
1956. Effect of ripeness on the viability of sugar, Jeffrey, and ponderosa pine seed. IN: Soc. of Amer. Forest. Proc., Portland, Oreg. 1955: 67-69.

21. Stoeckler, J. H., and G. W. Jones.
1957. Forest nursery practice in the Lake States. U.S. Dep. Agr., Agr. Handb. 110, 124 pp.

22. U.S. Department of Agriculture.
1948. Woody plant seed manual. Misc. Pub. 654, 416 pp.

23. Wakeley, Philip C.
1954. Planting the southern pines. U.S. Dep. Agr., Agr. Monogr. 18, 233 pp.

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-59 1967

PRODUCTIVITY INDICATORS IN WESTERN LARCH FORESTS[1]

Arthur L. Roe
Principal Silviculturist

ABSTRACT

Classification of land productivity, often neglected because of complexities in the conventional site index methods, can be done simply in larch forests by using plant indicators. Western larch (*Larix occidentalis* Nutt.) stands growing on several of the ecological habitat types as defined by Daubenmire have significantly different mean site indices. The habitat method will not replace the more precise conventional site index determination for individual stands.

Classification of land productivity is an important management tool that is often neglected because it is difficult to measure under varying stocking conditions in forests. Site index, a common means of rating forest land productivity, is ordinarily determined by measuring dominant and codominant trees in normally stocked stands. Trees must be measured in the same proportion of dominance classes as that found in the data from which the site curves were made. Site index is then determined from the height-over-age curves by extrapolating to an index age (50 years for western larch (*Larix occidentalis* Nutt.)).

---

[1]Special acknowledgment is due the J. Neils Lumber Company for valuable assistance in planning the study and collecting the data.

Current management studies show that ecological habitat types,[2] which can be easily and quickly recognized on the ground, provide a practical tool for broadly classifying productivity of larch stands. The method is also useful on areas that are denuded or where too few site trees are present. Daubenmire has developed a concise, practical guide[3] as an aid in classifying ecological habitat types, for such types serve as vegetative indicators of site quality.

COLLECTION OF DATA

The data reported here were collected on 363 plots during a survey of larch pole trees throughout western Montana, northern Idaho, and northeastern Washington to determine significant management factors. In each stand sampled, one or more trees that contained a transmission pole were selected as plot centers. Detailed measurements were then made on these sample trees, while site information was determined on concentric .2-, .1-, and .001-acre plots, using each sample tree as a common center. The ecological habitat type[4] was determined by examining the vegetation on each .2-acre plot and in the immediate vicinity. The ecological habitat type on each plot was classified by one of several persons trained to recognize such types. Although the habitat types were developed in northern Idaho and adjacent Washington, our experience indicates that they can be identified in western Montana as well. Two to four average dominant larch site trees, including the sample tree, were selected; d.b.h., total age and total height were recorded. Site index (the total height at age 50 years) was determined for each plot by extrapolation on unpublished height/age curves developed from normal plot data collected by L. J. Cummings in 1937.[5] These data form the basis for the analysis in this report.

ANALYSIS OF DATA AND RESULTS

Difference in mean site indices between all ecological habitat types was shown by "t" tests to be highly significant except between Thuja Tsuga/Pachistima, Thuja/Pachistima, and Abies grandis/Pachistima. Because these three types are moist, highly productive sites, the data were combined, and the mean of the combined types was significantly different from means of all the other types. The mean site indices for ecological habitat types are tabulated below:

---

[2] Daubenmire, R. Forest vegetation in northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification. Ecol. Monogr. 22: 301-330. 1952.

[3] Daubenmire, R. The use of vegetative indicators in the forests of northern Idaho and northeastern Washington. Typewritten, unpub., 3 pp., Wash. State Univ., Pullman, Wash. (n.d.)

[4] Ibid.

[5] Cummings, L. J. Larch-Douglas fir board-foot yield tables. U.S. Forest Serv. Northern Rocky Mountain Forest and Range Exp. Sta., Applied Forestry Notes 78, 3 pp.+, illus. 1937.

Ecological habitat type	Mean site index	Confidence interval P = .99
Picea-Abies/Xerophyllum	49.1	±2.08
Picea-Abies/Pachistima	58.2	±2.56
Thuja-Tsuga/Pachistima)		
Thuja/Pachistima)	66.3	±1.35
Abies grandis/Pachistima)		
Pseudotsuga/Physocarpus	62.2	±4.46
Pseudotsuga/Calamagrostis	54.6	±1.50

Covariance analysis of the site tree data confirms the above analysis. Ages in the stand sampled ranged from about 30 to more than 200 years. Errors may have been introduced into the plot site index determinations when the plot heights for the broad age ranges were extrapolated by means of average-height-over-age curves. Nevertheless, the mean total height of the site trees also showed a highly significant difference when adjusted for age differences by covariance methods between habitat types. Furthermore, it is interesting to note that this analysis suggests polymorphism among the height-over-age curves for the several habitat types. As illustrated in the summary of the analysis shown in table 1, the variation among regression coefficients was significant.

Hundred-year-old western larch crop trees reach an average total height of about 108 feet in the highly productive Thuja Tsuga/Pachistima and Abies grandis/Pachistima habitat types. On the other hand, crop trees of the same age in the relatively dry, cool Picea-Abies/Xerophyllum habitat type average slightly less than 84 feet. Heights reached by larch crop trees in the other habitat types fall between these extremes.

Table 1.--Summary of covariance analysis of height over age by habitat type

Source of variation	d.f.	Deviations from regression: Sums of squares	Mean squares	F.
Within	1059	359.92674		
Regression coefficient	6	13.64455	2.27409	6.483 significant
Common regression	1065	373.57129	.35077	
Means	6	115.83943	19.30657	55.041 highly significant
Total	1071	489.41072		

DISCUSSION

The ecological habitat classification cannot replace the more precise conventional method of determining site index for individual stands because site indices vary considerably within each of the ecological habitat types. Our belief in the usefulness of this classification as a management tool is supported by the fact that even though several persons classified plot vegetation in this study, the data produced highly significant results. Development of individual growth curves for habitat types might refine the estimate of productivity. In its present form, the habitat method provides a simple, useful means of rapidly assessing the relative productivity of large areas. Further refinement would require more data, which would only increase the complexity of its use.

AF PS, Ogden, Utah

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

U.S. Forest Service
Research Note INT-60 1967

ECONOMICAL AND RELIABLE ESTIMATES OF GENERAL COMBINING ABILITY FOR BLISTER RUST RESISTANCE OBTAINED WITH MIXED-POLLEN CROSSES[1]

R. T. Bingham[2]

ABSTRACT

Two kinds of mixed-pollen crosses (using equal volumes of fresh pollen from either 4 or 10 trees) and a series of four individual-pollen test crosses were made on 16 western white pine (Pinus monticola Dougl.) trees. Seedling progenies were exposed to the white pine blister rust disease and percentages of seedlings remaining healthy in the mixed-pollen progenies were compared with percentages observed for the average of the four individual-pollen crosses made on the same trees. Ten-pollen mix cross percentages were significantly and strongly correlated with average percentages from the four crosses, and fell within ±3 percent in 19 out of 20 cases. It was concluded that for estimating general combining ability for blister rust resistance, mixed-pollen crosses (with 10 or more pollens) were an economical and reliable substitute for the more conventional but expensive multiple crosses.

Forest geneticists at several stations in the United States and abroad are using or proposing a series of three to five individual, controlled crosses for appraisal of general combining ability of plus trees. Selection of the best plus trees may be aimed at improvement of pest resistance, growth rate, stem form, branching habit, or wood-quality traits; whatever the aim, these multicross progeny tests are quite expensive. For example, in appraisal of general combining ability for blister rust resistance[3]--a relatively short-term project running only 6 to 7 years from pollination--the cost for a four-cross test has averaged $600 per tree. We need to reduce this cost before undertaking any further practical testing on a large scale.

---

[1] This note is a nontechnical condensation of a research paper (Breeding blister rust resistant western white pine. IV. Mixed-pollen crosses for appraisal of general combining ability), which the author soon will submit to Silvae Genetica. Details of methods and analyses are given in the research paper. This summary is provided in advance because large savings in costs of progeny tests are possible through use of mixed-pollen crosses, and practical tree breeders may wish to effect these savings immediately.

[2] Principal Plant Geneticist, headquartered at Forestry Sciences Laboratory, Moscow, Idaho, which is maintained in cooperation with the University of Idaho.

[3] Here, specifically, the transmission of above-average resistance by phenotypically resistant plus trees (rust-free but as yet untested trees from heavily infected natural stands) when pollinated with a number of similar plus trees.

One obvious way to pare the costs of progeny testing is to substitute mixed-pollen crosses for the conventional series of individual crosses. This substitution has been suggested by Goddard, Peters, and Strickland,[4] but evidence as to the relative reliability of the mixed-pollen crosses is lacking. Thus reliability criteria for mixed-pollen crosses reported here may be of general interest to practical tree breeders.

MATERIALS AND METHODS

Sixteen blister rust-resistant western white pine (Pinus monticola Dougl.) plus (cankerfree) trees in five heavily infected natural stands in northern Idaho were crossed as shown in table 1, using fresh pollens. Of the 16, 11 trees were crossed in 1961; 5 more were crossed in 1962.

Seed from 66 (11 X 6) test progenies were sown in fall 1962, and from 30 (5 X 6) progenies in fall 1963. A sowing design of 10 randomized blocks was used, each progeny being represented by one 16-seed plot in each block. Seedling progenies were inoculated with the blister rust fungus in 1963 and 1964 in the fall, and the final inspection for active blister rust stem lesions was made in the fall of 1965. Fourteen ordinary, nonresistant control progenies were sown--six in 1962 and eight in 1963; these were sown, inoculated, and examined in the same manner as the test progenies.

Table 1.--Controlled crosses made to check reliability of mixed-pollen crosses

Cross no.	Pollination	Term for type of cross
1	Plus tree X a single ♂ tester)	Standard cross (average of four individual crosses)
2	Same plus tree X 2nd single ♂ tester)	
3	Same plus tree X 3rd single ♂ tester)	
4	Same plus tree X 4th single ♂ tester)	
5	Same plus tree X equal-volume mix of pollens of the four testers above	4-pollen cross
6	Same plus tree X equal-volume mix of pollens of four testers above along with six other testers	10-pollen cross

RESULTS AND DISCUSSION

At the final rust examination, the average 16-seed plot contained 12.6 seedlings. Overall success of inoculation was excellent; only 3 percent of the 1962-sown and 8 percent of the 1963-sown control seedlings remained healthy (free of active blister rust cankers). Despite the high average level of infection, localized variation in level of infection was noticeable between replicates (plots) of the same plus tree or control progeny.

Percentages of healthy seedlings remaining in progenies of the three types of crosses, for each of the 16 plus trees, are shown in table 2 (columns 3, 6, and 10). The standard cross values are mean percentages (40-plot, unweighted averages), arising from four individual tester crosses made on the plus tree. (Percentages are adjusted to prevent discontinuities caused by small numbers of seedlings per plot. See Bartlett, M. S., J. Roy. Statist. Soc. Suppl. 3: 63-78, 1936.) The standard cross values are considered to give the most reliable estimates of general combining ability that we can obtain, in view of cost. Even so, they are not highly accurate, as witnessed by their relatively large standard errors (computed elsewhere, they average about one-fourth as large as the standard cross mean percentages to which they apply). From analysis of variance we know that for the standard crosses, error variance is only about one-twentieth the variance attributable to the plus trees, whereas for the two mixed-pollen crosses it amounts to almost one-fourth of that of the plus trees. This larger proportion of error variance probably reflects the much smaller number of replicates used for the mixed-pollen cross tests (10 plots vs. 40 in the standard crosses). Also, we know that the method of inoculation, which employed Ribes bushes, often bearing large numbers of either heavily or lightly infected leaves, resulted in wide variation in infection between plots (see footnote 1).

[4] Goddard, R. E., W. J. Peters, and R. K. Strickland. Cooperative forest genetics research program. Fourth Prog. Rep., Univ. Fla. Sch. Forest. Res. Rep. 7, 16 pp., 1962.

Table 2. --Percentages of healthy seedlings in progenies of the standard and the mixed-pollen crosses

	Standard cross			4-pollen cross				10-pollen cross			
Plus tree (1)	No. of trees tested (2)	Proportion healthy (3)	Ranking within best half (4)	No. of trees tested (5)	Proportion healthy (6)	Diff. from standard cross (7)	Ranking within best half (8)	No. of trees tested (9)	Proportion healthy (10)	Diff. from standard cross (11)	Ranking within best half (12)
		Percent			Percent	Percent			Percent	Percent	
1962 TEST OF 11 PLUS TREES											
61	511	10.5	5	120	13.0	+ 2.5	5	130	15.9	+ 5.4	2
69	439	11.8	4	95	13.4	+ 1.6	4	120	14.9	+ 3.1	4
70	476	7.6		113	15.2	+ 7.6	2	130	7.1	- 0.5	
224	585	4.9		149	2.2	- 2.7		147	4.4	- 0.5	
257	591	4.3		146	2.8	- 1.5		128	4.9	+ 0.6	
264	280	18.1	1	82	15.1	- 3.0	3	42	20.1	+ 2.0	1
266	534	9.0		143	12.3	+ 3.3		146	9.3	+ 0.3	
268	560	4.9		139	8.4	+ 3.5		143	3.4	- 1.5	
272	578	13.6	2	111	10.8	- 2.8		135	14.9	+ 1.3	3
276	291	13.2	3	57	20.3	+ 7.1	1	119	9.9	- 3.3	5
277	573	2.7		149	2.8	+ 0.1		133	3.6	+ 0.9	
						+25.7				+13.6	
						-10.0				- 5.8	
						+15.7				+ 7.8	
Means	492.5	9.1		118.5	10.6	+ 1.4		124.8	9.8	+ 0.7	
1963 TEST OF 5 PLUS TREES											
336	479	14.5		150	8.1	- 6.4		129	13.6	- 0.9	2
353	545	16.2	1	124	12.4	- 3.8	2	138	12.8	- 3.4	
362	491	12.0		135	10.4	- 1.6		141	10.0	- 2.0	
363	406	10.7		139	10.5	- 0.2		132	8.6	- 2.1	
367	546	14.9	2	140	14.5	- 0.4	1	121	16.8	+ 1.9	1
						+ 0.0				+ 1.9	
						-12.4				- 8.4	
						-12.4				- 6.5	
Means	493.4	13.7		137.6	11.2	- 2.5		132.2	12.4	- 1.3	
Pooled correlation coefficients for 1962 and 1963 tests (13 d.f.)[1]											
Product-moment (r)					0.785				0.919		
Rank, calculated from complete rankings (r_s)							0.879				0.956

[1]All correlation coefficients are significant at the 1-percent level of probability.

Nevertheless, table 2 shows that for most of the 16 plus trees tested, percentages of healthy seedlings found in mixed-pollen cross progenies are similar to those found in corresponding standard crosses. Closeness of the relationship is indicated by the product-moment and rank correlation coefficients given at the bottom of the table. These indicate that mixed-pollen percentages are significantly correlated with the standard cross percentages, and that the 10-pollen cross percentages ($r = 0.918$, $r_s = 0.956$) are strongly correlated.

In order to define the relative accuracy of the 4-pollen or 10-pollen crosses, however, we must resort to another sort of analysis. Here we use the specialized chi-square analysis proposed by Freese,[5] wherein accuracy of a new technique can be estimated from the difference between the results "observed" under the new technique (mixed-pollen crosses) and those "expected" under the presumably more accurate standard technique (the standard cross). An important feature of Freese's analysis is that acceptable levels of accuracy are imposed. Realizing that the standard cross values themselves were not without error, and that the practical selectionist could accept and use levels of accuracy below those desirable for critical research, we specified that to be "reliable," mixed-pollen cross values should fall within ±3 percent in the standard cross values, in 95 out of 100 cases. Another feature of the analysis is that bias--here signified by an excess of plus differences in the 1962 test, and of minus differences in the 1963 test (table 2)--can be eliminated as a cause for rejecting the new technique as inaccurate.

The chi-square analysis was performed, with percentages transformed to corresponding arc-sins as is usual with binomial (percentage) data. It showed that of the two "new techniques," only the 10-pollen cross met the established reliability criteria. This meant that there was only a 1-in-20 chance that the values of the 10-pollen cross would not fall within 3 percent of those obtained for the same plus tree by the more reliable but more expensive standard cross. For example, the 10-pollen cross value for plus tree 272 (table 2, column 10) of 14.9 percent should fall, in 95 of 100 cases, within ±3 percent of the corresponding standard cross value (column 3, 13.6 percent) for that tree, or within the range of 10.6 to 16.6 percent.

What are the implications of these findings for the practical tree breeder concerned with rust resistance? We see three implications as follows:

First. Mixed-pollen crosses which include 10 or more fresh pollens can be used to obtain economical, yet relatively reliable estimates of general combining ability. If, for example, the tree breeder were to select from table 2 the top-ranking half, or five, of the eleven plus trees of the 1962 test on the basis of the 10-pollen cross, he would choose trees 61, 69, 264, 272, and 276. Similarly, in the five-tree 1962 test he would choose two trees (336 and 367). Then, considering the standard cross results to be more reliable, he would have made only one error in his selection (choice of tree 336). Such "errors" in selection would occur only near the selection cutoff point where, with the 3-percent accuracy of the new technique, he should expect them. Furthermore, in choosing 336 as one of two trees chosen in the 1963 test, he is not 50 percent (one out of two trees) in error. Instead, near the cutoff point he has selected one tree almost, but not quite, as good, and culled one almost, but not quite, as poor as the trees he would have selected using the standard crosses.

Second. Wide variation in intensity of inoculation and infection between plots should be reduced, or the number of plots (and thus the cost) increased in mixed-pollen cross testing. We intend to concentrate on securing uniform inoculation--by random placement of rust-infected *Ribes* spp. leaves, not bushes, over the small plots in the test nursery.

Third. Although the mixed-pollen crosses are economical, the breeder using them must be willing to sacrifice (a) some accuracy in selection, and (b) the recognition of specific combining ability.[6] By using 10 or more pollens in the mixed-pollen crosses, along with the improved inoculation techniques, we expect to lower testing costs from about $600 to $150 per selection.

---

[5] Freese, Frank. Testing accuracy. Forest Sci. 6(2): 139-145. 1960.

[6] The ability of specific, resistant plus trees to transmit above-average resistance to their offspring, but only when mated with certain other specific, resistant plus trees.

Research Note

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

U.S. Forest Service
Research Note INT-61

1967

EFFECT OF EXPOSURE AND LOGGING ON RUNOFF AND EROSION

Nedavia Bethlahmy[1]

ABSTRACT

High-intensity rainfall was applied artificially to plots on eight steep, forested areas in the Payette National Forest in central Idaho. Logged and unlogged sites on northeast and southwest exposures were represented equally. Results show that runoff and erosion are greater on southwest than on northeast exposures, and that even after careful logging, erosion increases on southwest but not significantly on northeast exposures.

The steep, forested mountains of central Idaho are an important source of water, but little is known about the hydrologic characteristics of their soils. Information is greatly needed, because formerly inviolate areas are increasingly subject to logging, road construction, and other influences which may well alter the hydrologic regime of watersheds and their soil mantles.

The hydrologic regime is affected also by environmental features, especially the exposure of the terrain. Logging is a human activity subject to controls, but terrain exposure must be accepted as immutable. In central Idaho, as in many other regions, areas of contrasting exposure are strikingly dissimilar, even to the casual observer.

This study investigates the effects of both logging and differences in exposure on runoff and erosion under high-intensity simulated rainfall.[2]

---

[1]Principal Forest Hydrologist, headquartered at Boise, Idaho.

[2]The author thanks Richard Meeuwig, Intermountain Forest and Range Experiment Station, and his field assistants, headquartered at Logan, Utah, for performing all laboratory analyses and for help in conducting field infiltration runs.

STUDY AREA AND METHODS

The study was conducted in the Zena Creek Sale Area of the Payette National Forest in central Idaho. Tree cover is ponderosa pine and Douglas-fir; the sandy soil, derived from the granitic Idaho batholith, is generally shallow and coarse in texture.

Eight areas within the sale unit were selected, and in these, contrasting exposure and treatment were equally represented. Exposures were generally northeast and southwest, and the areas were either logged or unlogged. In logging, small groups of trees were selected for cutting; slash was lopped and scattered. Four infiltration study plots were established in each of the eight areas. Vegetal cover varied among plots, but was generally more dense on plots on north-facing slopes. Similarly, steepness of slope varied, but was greater on north-facing slopes.

All 32 plots were located not more than 500 feet from one of two logging roads, because the Rocky Mountain Infiltrometer[3] that we used was very bulky and the terrain was steep.

Simulated rainfall was applied to each plot (50.8 X 77.5 cm.) for 30 minutes at a rate of approximately 12.2 cm. per hour. Applied rainfall and runoff were measured at the end of every 5 minutes and eroded soil material was measured after 30 minutes.

METHOD OF ANALYSIS OF DATA

The data gathered in the study were subjected to analysis with the aim of answering a series of questions suggested by the theme of the study. Appropriate statistical techniques were employed, including analysis of variance, regression analysis, covariance analysis, and multiple covariance analysis.[4] Two variables used in the study required transformations. A logarithmic transformation was tested and found appropriate for the erosion data, and the percent of bare soil was transformed to arc sin (percent bare)$^{\frac{1}{2}}$.

RESULTS

The questions to be answered by the study are these:

1. Is the amount of erosion related to the amount of runoff?

2. Is runoff related to exposure?

3. Is runoff related to logging?

---

[3] Dortignac, E. J. Design and operation of Rocky Mountain Infiltrometer. Rocky Mountain Forest and Range Exp. Sta., Sta. Pap. 5, 68 pp., illus. 1951.

[4] Snedecor, George W. Statistical methods, 5th ed., 534 pp. Ames, Iowa: The Iowa State College Press. 1959.

Finding the answers to the questions required consideration of the effects of differences in intensity of applied rainfall, in steepness of terrain, and in percent of bare soil. A summary of data on all these variables averaged for each group of eight plots, is given in table 1. Specific findings on the three questions are described below.

EROSION AND RUNOFF

The amount of erosion is related to the amount of runoff, as shown by the study. The relation is expressed in the following equation:

$$\log_e E = 1.35R - 0.77 \qquad (1)$$

where E is erosion in grams and R is runoff in centimeters. The equation was derived from total erosion and total runoff from each of the 32 plots after 30 minutes of simulated rainfall. The correlation coefficient between E and R was found to be 0.83; this is statistically significant at the 1-percent level of probability. Under the conditions of the experiment, the amount of soil eroded is therefore closely related to the quantity of surface runoff.

Equation 1 was developed from the pooled field data, without regard to the fact that data were gathered from plots representing four combinations of exposure and treatment (northeast exposure, logged and unlogged; southwest exposure, logged and unlogged). A covariance analysis was used to test the possibility that separate equations for each combination would differ from equation 1. This analysis indicated that the equation is a valid representation of the relation between erosion and runoff in the study area.

Table 1.--Values[1] of variables measured in study of 32 plots.

Plot group	Applied rainfall	Surface condition: Slope	Surface condition: Bare soil	Runoff	Sediment
	Cm./30 min.	Percent	Percent	Cm./30 min.	Gr./30 min.
Southwest exposure:					
Logged	6.073 ± .117	69.4 ± 3.8	55.6 ± 1.1	3.721 ± .292	170.6 ± 46.9
Unlogged	6.284 ± .076	46.5 ± 4.8	28.2 ± 9.5	2.090 ± .587	39.7 ± 24.5
Northeast exposure:					
Logged	6.060 ± .091	72.6 ± 4.5	4.5 ± 2.9	.536 ± .117	9.6 ± 8.0
Unlogged	5.982 ± .107	73.9 ± 2.5	.9 ± 0.6	.861 ± .196	2.9 ± 1.33

[1] Values are averaged with respective standard errors for each group of eight plots representing a specific combination of exposure and treatment.

RELATION OF RUNOFF AND EROSION TO EXPOSURE AND LOGGING

Runoff is related to exposure, as shown by a covariance analysis of data on runoff and applied rainfall. The intensity of the artificial rainfall applied to the plots varied slightly, due to performance of the equipment; the average measured intensity was 0.399 inch or 1.01 cm. per 5 minutes, with a standard deviation of 0.037 inch or 0.09 cm. To minimize any error attributable to variations in rainfall intensity, an equation was developed for each plot:

$$R_t = a + bP_t T(T+1)^{-1} \qquad (2)$$

where R_t is runoff in centimeters during a 5-minute period, and P_t is applied rainfall at time T minutes from the beginning of rainfall application. (The minimum value of T is 5 minutes, and the maximum value is 30 minutes.) Analysis of the resulting 32 equations showed that plots having northeast and southwest exposures have different runoff patterns. The regression coefficients of the equations characterizing runoff from the two exposures differed at the 1-percent level of probability:

$$\text{NE exposure: } R_n = 0.25X - 0.11 \qquad (3)$$

$$\text{SW exposure: } R_s = 1.17X - 0.63 \qquad (4)$$

where R represents runoff in centimeters during a 5-minute interval, and X represents the product of the rainfall and time variables shown in equation 2; it is limited in this study to values between 0.61 and 1.25.

At an average rainfall intensity of 0.399 inch or 1.01 cm. per 5 minutes, runoff from plots having southwest exposure exceeded that of plots having northeast exposure by a substantial amount. Average values for runoff in centimeters are as follows:

Exposure	Time (minutes)	
	0-5	25-30
Southwest	0.36	0.52
Northeast	0.10	0.14

More runoff occurred from southwest-facing plots despite the fact that they were, on the average, less steep than the northeast-facing plots (57.9 percent slope compared to 73.2 percent slope--see table 1, average for logged and unlogged plots).

Southwest-facing plots were considerably more bare than northeast-facing plots (average of 41.9 percent bare ground compared to 2.7 percent). To test the importance of this fact, we made a covariance analysis of runoff data for the two exposures in relation to the percent of bare soil on each plot. The result indicated that runoff is directly related to the amount of bare soil: that is, if northeast and southwest exposures were equally bare, they could be expected to show equal amounts of runoff, but this situation seldom if ever occurs.

Runoff is related to logging, but when considered with respect to degree of slope and amount of bare soil, the relation is valid only for plots having southwest exposure. Because runoff characteristics were found to differ according to plot exposure, plot groups of northeast and southwest exposure were analyzed separately to determine the effects of logging.

Southwest exposures.--Before the covariance analysis was made, adjustments were made as before for variations in rainfall intensity, using equation (2). The analysis showed that logged plots yielded more runoff than unlogged plots did, at the 1-percent level of probability. The equations are as follows:

$$\text{Logged:} \quad R_l = 1.17X - 0.50 \qquad (5)$$

$$\text{Unlogged:} \quad R_{ul} = 1.17X - 0.77 \qquad (6)$$

where R and X are as defined earlier. Inspection of these equations reveals that runoff from logged plots exceeds that from unlogged plots by 0.27 cm. (per 5-minute period). However, the logged plots were both steeper (69.4 percent slope compared to 46.5 percent) and more bare (55.6 percent bare ground compared to 28.2 percent) than the unlogged plots. Adjustments were made to compensate for these differences; the covariance analysis indicated that logged plots still yielded larger quantities of runoff than did unlogged plots.

Northeast exposures.--A similar series of analyses was performed for plots having northeast exposure. After adjustment for rainfall intensity only, data indicated that unlogged plots yielded more runoff than logged plots; however, after further adjustment for differences in slope and bare ground, the data indicated that logged and unlogged plots of northeast exposure can be expected to yield equal amounts of runoff.

RELATION OF EROSION TO EXPOSURE AND LOGGING

The preceding analyses indicate that erosion is related to runoff; that plots with southwest exposure yield more runoff than those with northeast exposure; and that on southwest-facing slopes logged plots yield greater runoff than unlogged plots. These conclusions suggest that the erosion pattern is similar to the runoff pattern, and analyses bear this out.

Analysis of variance shows that plots with southwest exposure yield more sediment than those with northeast exposure (1-percent level of probability), and that logging is related to increased erosion only on southwest-facing slopes (5-percent level of probability). Adjustment (by multiple covariance analysis) for plot differences in amount of bare soil and degree of slope did not cause any change in the conclusion.

DISCUSSION

The results of the study have implications for practical management of the land and for further research. Significant relations are indicated between erosion and runoff, between erosion and exposure and logging, and between erosion and soil characteristics.

1. Erosion and runoff.--Analyses show that erosion can be expressed as a logarithmic function of runoff, as in equation

$$\log_e E = 1.35R - 0.77$$

The equation is highly significant for land management, since a slight increase in 30-minute runoff, as from 1 cm. to 2 cm., results in almost a fourfold increase in erosion, from 1.8 grams to 6.9 grams. Thus, any land management practice which increases runoff may bring about a very large increase in erosion. The land manager must bear this relation in mind when weighing the consequences of proposed use of land.

2. Erosion as related to exposure and logging.--Analyses show that in the study area erosion is related to terrain exposure. Under the impact of intense rainfall, erosion from plots having southwest exposures greatly exceeds that from plots having northeast exposures. The effect of logging, even when this is carefully done, as it was in the study area, is to magnify the difference severalfold. The number of trees on southwest-facing plots is small, and lopping and scattering logging debris does not overcome the effects of the logging activities; on northeast-facing slopes, tree density is much greater, and the removal of a few selected stems, with subsequent scattering of logging debris, appears to compensate fully for possible land damage from logging activities.

The pronounced effect of even light logging on erosion from southwest-facing plots emphasizes the problem confronting the forest manager. Merchantable timber is found on south slopes, yet logging activity may result in a phenomenal increase in erosion.

3. Erosion and soils.--It has been shown here that in an experimental logging area in the mountainous region of central Idaho, the erosion-inducing effect of high-intensity rainfall varies, depending on exposure; it is greater on southwest-facing slopes than on northeast-facing slopes. We may hypothesize that soil differences associated with slope and topography are a major contributing element.

Differences between the climatic environments of north and south exposures are accentuated in mountainous areas, and ultimately result in soils whose characteristics are noticeably divergent. Although surface characteristics (such as degree of slope or amount of bare soil) may at times strongly influence erosion, the fundamental reason for differences in rates of erosion may lie in the nature of the soil.

In an analysis of variance, a partitioning of the soil erosion sums of squares for the four different combinations of exposure and treatment shows that a certain portion of these sums can be explained by degree of slope, and that this explained portion can be increased if both degree of slope and amount of bare soil are considered jointly.

The figures are as follows:

Exposure and treatment	Sums of squares accounted for by	
	Slope alone	Slope and bare soil
	(Percent)	
Northeast		
Logged	19	41
Unlogged	15	65
Southwest		
Logged	4	90*
Unlogged	89*	97**

*Significant at 5-percent level of probability.
**Significant at 1-percent level of probability.

This tabulation shows that slope gradient in conjunction with the amount of bare soil accounts for a highly significant amount of the total variation in soil erosion on southwest-facing plots. On northeast-facing plots the proportion is not statistically significant, but may be of practical importance. It may well be that certain soil characteristics are strongly correlated with slope and amount of bare soil, and that these characteristics may ultimately be defined in such a manner as to explain the variation in erosion. Further research along these lines is indicated.

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, co-operation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-62 1967

DISTRIBUTION OF BARK BEETLE ATTACKS ON PONDEROSA PINE TREES IN MONTANA

Philip C. Johnson[1]

ABSTRACT

The boles of 71 mature ponderosa pine trees killed by Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae) were analyzed to determine the distribution of the attacks by endemic populations of this bark beetle and those of several phloem-feeding associates. The longitudinal-circumferential distribution of the attacks fitted diagrammatically into four distinguishable bole infestation patterns. The characteristics of the patterns and similarities with comparable attacks of D. brevicomis in northeastern California are discussed.

Forest entomologists studying the western pine beetle (Dendroctonus brevicomis LeConte (Coleoptera: Scolytidae)) have periodically investigated the feasibility of predicting changes in population levels and consequent outbreak patterns by using measurable field factors. One approach to this objective has been to study the identity and dependability of the attack patterns made by this insect and its principal phloem-feeding insect associates on the boles of ponderosa pine host trees. Studies as early as 1912 in California[2] showed that attacks by the pine beetle produce distinctive distribution patterns on the boles of these trees during endemic and epidemic cycles of its populations. Attack patterns differ between individual host trees of varying ages and degrees of vigor and between geographic areas. The pattern is also affected by the particular combination of associated insects that attack the tree, by the season of the attack, and by the density of the pine beetle population.

---

[1]Principal Entomologist, headquartered at Forestry Sciences Laboratory, Missoula, Montana, which is maintained in cooperation with the University of Montana.

[2]Miller, J. M., and F. P. Keen. Biology and control of the western pine beetle. U.S. Dep. Agr. Misc. Pub. 800. 381 pp. 1960.

Since the complex of bark beetles found attacking ponderosa pine in parts of California differs from that found in the northern Rocky Mountains, it seemed likely that the bole attack patterns would also differ. To identify and describe the characteristic patterns, a study was conducted between 1949 and 1964 in mature forests of ponderosa pine in Montana west of the Continental Divide.

METHODS

Newly killed ponderosa pine trees were located and measured annually for 15 years on 35 plots totaling 560 acres and containing 11,946 living pine trees in stands classified as mature or overmature. As part of a concurrent study, the living trees had already been measured for gross board-foot volume and had been classified by age, general vigor, and risk of attack by *Dendroctonus brevicomis*. Age and vigor classes were based on the Ponderosa Pine Tree Classification[3] and risk rating was determined by the Ponderosa Pine Risk Rating System.[4]

The tree-mortality measurements made annually during the autumn months revealed a total of 98 ponderosa pine trees that had died during the study period, presumably from attacks of *D. brevicomis*. Each of these trees was felled and examined within a year after death. The boles of the trees were analyzed to determine the cause of death and the distribution and other features of the attacks by *D. brevicomis* and its associates.

For the analysis, irregular sections of bark, each amounting to 0.5 square foot, were removed from the north, east, south, and west sides at 10-foot intervals along the boles of the felled trees. The inner surfaces of the bark samples were first examined generally for egg galleries and larval mines of *D. brevicomis* and other phloem-feeding insects. The examinations disclosed that 27 of the 98 felled pine trees died from causes other than attacks by *D. brevicomis*. The remaining 71 pine trees had been attacked and killed by *D. brevicomis* alone or in conjunction with attacks of insect associates.

The areas of cambium attacked by each species of insect in the 71 beetle-killed trees were then specifically located and their extent was determined by further examinations between the sampling points when necessary. Results were sketched on bole diagrams. Areas of cambium that were unattacked or had been dead for two or more years previous to the analyses were also measured and sketched.

The bole diagrams for the 71 beetle-killed pine trees were separated according to three diameter classes to disclose any possible relation of attack patterns to age classes and sizes. Basal diameter classes of 12 to 18 inches, 20 to 28 inches, and 30 to 54 inches

---

[3] Keen, F. P. Ponderosa pine tree classes redefined. J. Forest. 41(4): 249-253. 1943.

[4] Salman, K. A., and J. W. Bongberg. Logging high risk trees to control insects in pine stands in northeastern California. J. Forest. 40(7): 533-539. 1942.

were used for the grouping. The diagrams were then studied to detect visually discernible bole infestation patterns, or types, within each diameter class. Four common types were seen to exist, and composite diagrams of these types were drawn.

An attempt was then made to draw a relation between these types and the age, vigor, and risk rating of the trees in each type group. To this end, the proportions of living and beetle-killed trees in the various age, vigor, and diameter classes and risk ratings were recorded.

RESULTS

The four reasonably distinctive bole infestation types identified in the study are represented by composite diagrams in figure 1. The diagrams show the mean linear and circumferential distribution of attacks by Dendroctonus brevicomis and the following species of phloem-feeding beetles:

Family Scolytidae
- Dendroctonus ponderosae Hopkins (=monticolae Hopkins)
- Ips pini (Say) (=oregonis (Eichhoff))
- Ips emarginatus (LeConte)

Family Buprestidae
- Melanophila californica Van Dyke

As evident in the diagrams, the species composition of the attack patterns and the distribution of the attacks by the several insect species differed slightly in the three diameter classes within bole infestation types I and II. Patterns of types I and II were found in trees of all three diameter classes, but types III and IV were found only in trees of a single diameter class.

Populations of D. brevicomis on the plots remained at endemic levels throughout the study. The mean annual gross mortality of ponderosa pine from beetle attacks during this period, for instance, was 24 board feet per acre, an amount believed to be well under the probable gross increment for mature ponderosa pine stands in this region.

There were no marked differences in salient characteristics of the trees classified under the four bole infestation types (table 1). There were, however, a few gross differences between the premortality characteristics of beetle-killed trees and those of the average living ponderosa pine trees on the plots used by the study:

Characteristics	Beetle-killed trees	Living trees
Age class	4	4
Vigor class	D	C
Risk rating	3 or 4	2
Gross board-foot volume	755	776

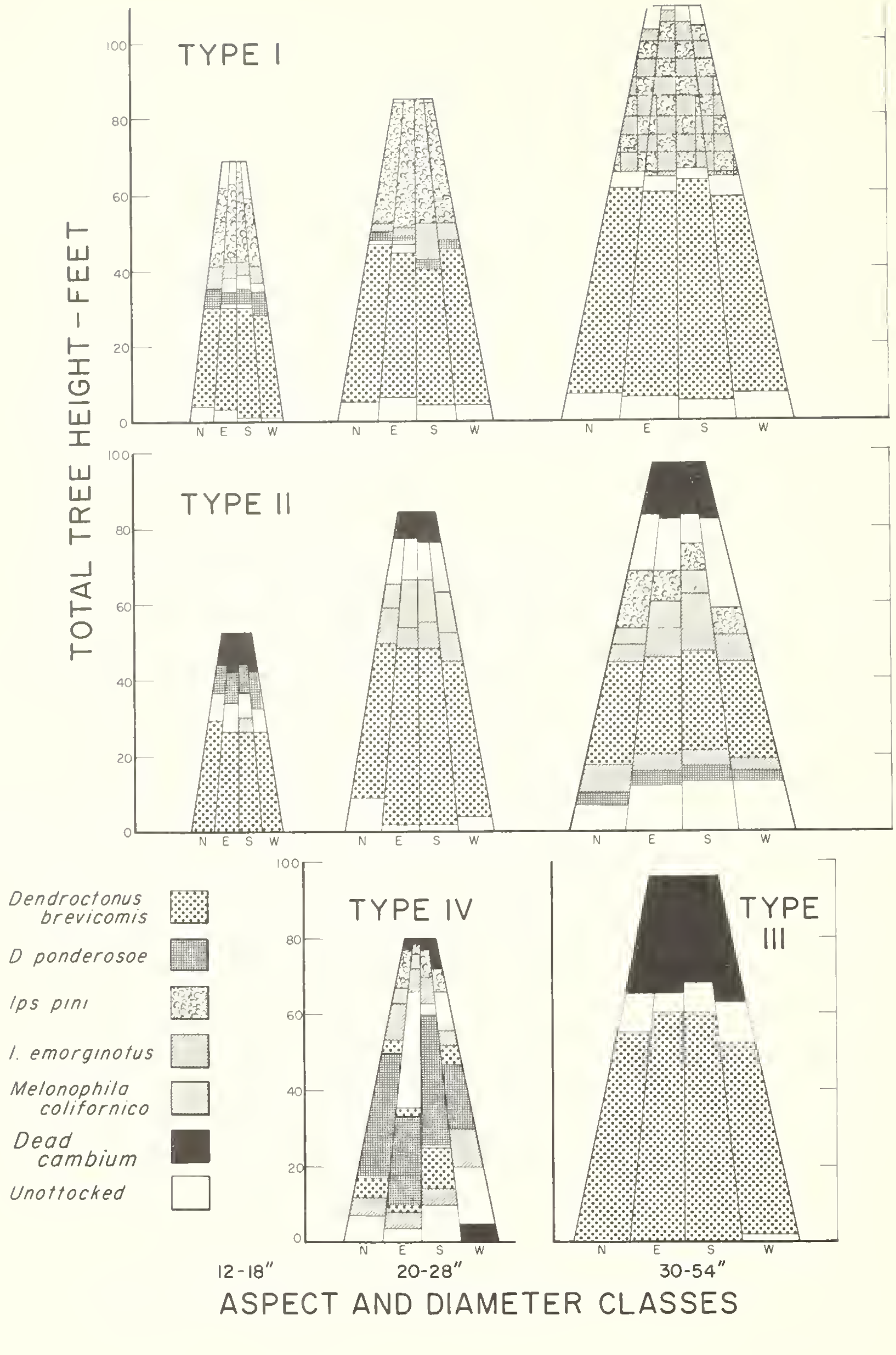


Figure 1.--Composite diagrams of four bole infestation types. The diagrams indicate the distributional patterns of attacks by endemic populations of Dendroctonus brevicomis and those of its principal phloem-feeding insect associates in mature ponderosa pine trees in western Montana from 1949 to 1964.

Table 1.--Some characteristics of beetle-killed ponderosa pine trees according to type of bole infestation pattern

Bole infestation type	Basal diameter class	Number of trees sampled	Mean tree size: Basal diameter	Mean tree size: Total height	Predominant classifications: Tree classification: Age[1]	Predominant classifications: Tree classification: Vigor[2]	Predominant classifications: Risk rating[3]
	Inches		Inches	Feet			
I	12-18	10	16	69	4	D	3
	20-28	18	24	85	4	C	2, 3
	30-54	12	37	109	4	C	3, 4
II	12-18	4	15	52	4	D	2, 3
	20-28	13	24	84	4	C, D	3
	30-54	4	36	67	4	C, D	2, 4
III	30-54	7	36	97	4	D	4
IV	20-28	3	25	80	4	C	2, 3, 4
		71					

[1] Age: 1, young; 2, immature; 3, mature; 4, overmature.
[2] Vigor: A, very good; B, good to fair; C, fair to poor; D, very poor.
[3] Risk (of beetle attack): 1, low; 2, moderate; 3, high; 4, very high.

Areas of cambium occupied by each insect species shown in figure 1 were usually occupied by that species exclusively. Areas occupied by D. brevicomis included scattered patches of uninfested cambium in many of the sampled trees. In contrast, areas occupied by Ips pini were completely utilized by its egg galleries or by the feeding of larvae or new adults.

By the time the beetle-killed trees were analyzed, most of them had been abandoned by the broods of D. brevicomis or the phloem-feeding insect associates that had developed in them. The former presence of the beetles was identified and dated by the relative state of deterioration of the phloem tissue as judged from experience by the writer, and by egg gallery and larval mine patterns inscribed on the inner bark surface.

A comparison of the bole infestation types observed in Montana with those from a comparable outbreak level and host forest condition in northeastern California, as reported by J. W. Johnson,[5] is given in table 2.

[5] Johnson, J. W. Composition studies of the 1941 season, Modoc National Forest. Unpubl. rep., U.S. Dep. Agr., Bur. Entomol. and Plant Quar., Berkeley, Calif. 13 pp. Dec. 17, 1940.

Table 2.--Comparison of distribution of types of bole infestation in trees studied in Montana and California

Type[1]	Dominant species	Distribution of trees studied: Montana 1949-1964	California 1939	California 1940
		Percent		
I	Dendroctonus brevicomis-Ips pini	56.3	45.7	14.3
II	Dendroctonus brevicomis-mixed species	29.6	8.6	2.4
III	Dendroctonus brevicomis	9.9	18.6	9.5
IV	Dendroctonus ponderosae-Dendroctonus brevicomis-mixed species	4.2	5.7	
V	Melanophila californica-Dendroctonus brevicomis		14.3	40.5
VI	Melanophila californica-Dendroctonus brevicomis-Ips pini		4.3	26.2
VII	Ips pini-Dendroctonus brevicomis		2.8	7.1
		100.0	100.0	100.0

[1] Roman numerals (V-VII) are assigned to California types for convenience.

From Johnson's diagrams and from the study observations, some general comparisons may be made. Although it plays an aggressive, tree-killing role in northeastern California (types V and VI), the buprestid Melanophila californica was almost unnoticeable as a secondary infester of mature ponderosa pine trees in western Montana during the study period. Similarly, the initial top-killing of mature ponderosa pine trees in California by Ips pini (type VII), followed by attacks on these trees by the western pine beetle, was not observed in Montana. Attacks of I. pini in Montana, while still confined largely to the upper boles of pine trees, almost always followed initial attacks by D. brevicomis. The remaining four bole infestation types previously identified in California (types I-IV) were recognized in western Montana.

DISCUSSION

Bole infestation types from endemic populations of *Dendroctonus brevicomis* in western Montana and northeastern California showed certain similarities, although this was not true of types from other parts of California. Bark beetle faunal complexes found in western Montana and northeastern California appear to be quite similar, even though the ponderosa pine stands in the two regions bear, in part, different forest cover type designations.[6] The study has made evident the following characteristics of bole attack patterns produced by endemic populations of *D. brevicomis* in western Montana:

1. The patterns indicate that ponderosa pine trees killed by the beetle are predominantly those classified as poorer in vigor and higher in risk of beetle attack than trees representative of the stands as a whole.

2. Endemic populations of *D. brevicomis* do not fully utilize the available bole cambium in the trees they attack. This may result more from the primary attraction of scattered host trees, which divides the low level populations of attacking pine beetles, than from interspecific competition from attacks of associated insects. From observation and from other studies, we know that attacks by these associates ordinarily follow those of the pine beetles after a time lag that would allow the available pine beetle population sufficient opportunity to utilize fully the acceptable cambium.

3. The attack characteristics in (2) above undoubtedly enable regionally important insect associates to utilize greater amounts of unattacked cambium for the development of their own broods in trees initially attacked by *D. brevicomis*.

4. Attacks of *D. brevicomis* in most host trees come within reach of persons standing at the base of the trees, a feature that facilitates identification of trees attacked by this insect.

---

[6] Western Montana: interior ponderosa pine and ponderosa pine--larch--Douglas-fir, types 237 and 214, respectively, of the Society of American Foresters. Northeastern California: interior ponderosa pine.

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-63

1967

TREE CHARACTERISTICS INFLUENCE 2 X 4 STUD YIELD OF LODGEPOLE PINE[1]

E. S. Kotok[2]

ABSTRACT

Acceptable yields of 2 X 4 studs in marketable grades can be recovered from lodgepole pine logs having certain characteristics. Severe defects seriously reduce yield of better grades of studs.

Lodgepole pine has been marketed successfully in a variety of lumber products. The uniform texture, characterized by small tight knots, and the relative straightness and lack of taper in trees have combined to make lodgepole an ideal species for ties, boards, and dimension lumber.

Lodgepole pine manufacturers, faced since 1960 with loss of the 1-inch board market to plywood and other sheet-formed material producers, have discovered that the species is especially well-suited for manufacture of 2 X 4 studs. Demand for these 8-foot framing members used in house construction has been increasing; as a result, many sawmills have been designed to produce studs exclusively.

Manufacturers are interested in the ratio of high- to low-grade material resulting from any production mix. The study reported here sought to determine the effect of several intrinsic and finite tree characteristics on the grade yield of lodgepole pine studs.

---

[1]This study was conducted in cooperation with the U.S. Forest Service Intermountain Region Office, the Targhee National Forest, and Idaho Stud Mills, Inc., of St. Anthony, Idaho.

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

GRADES AND SPECIFICATIONS FOR STUDS

Lodgepole pine studs used in this study were graded in accordance with the lumber grading rules of the Western Wood Products Association.[3] Lumber must meet Association standards of proper grading and stamping by certified lumber graders at the producing mill in order to compete on the national market.

Lumber grades are based on the size and location of knots, dimensions of the piece, straightness, and other features. The standards provide, according to grading rules, "a measure of value between mills manufacturing the same or similar woods, by harmonizing the differences existing between different stocks of lumber regardless of the character of the logs from which they were produced... ." Therefore, a given grade represents the same value and use regardless of its mill of origin.

The grades considered in this study were labeled "Construction" for the best lumber, "Standard" for better lumber, "Utility" for good lumber, and "Economy" for poor but usable lumber. These grades conform to national lumber sales specifications and are comparable to lumber grades of other regional producer associations.

The WWPA grading rules permit 1/4-inch crook or twist in Construction or better grade studs, 5/16-inch in Standard grade studs, and 3/8-inch in Utility grade. Because of certain needs in dry wall masonry construction, many architects and builders require the use of Standard and better grade studs, which conform to higher standards of straightness. Construction and Standard grade studs, being in greater demand, are most readily sold by manufacturers and bring the highest prices.

STUDY PROCEDURE

For this study, 119 trees were selected from more than 2,000 to represent woods-run lodgepole pine in the Targhee National Forest in Idaho. The range of natural tree qualities in lodgepole is relatively limited; so no extremely "rough" trees nor outstandingly superb trees were included. The resulting lumber grade yields closely approximated those experienced by industry in southeastern Idaho from a "good run of timber." From such stands, yields of 71 percent Standard and Construction from logs without defect are reasonable, just as unmerchantable yields of less than 5 percent are usual.

The seven tree characteristics investigated in this grade-yield study included short butt crook, stem crook, sweep, forked stems, eccentric pith, fluted butts, and spiral grain.[4] Additional logs containing none of these specified characteristics were included as a control sample. Each sample tree was selected to represent one characteristic and was color coded for this characteristic and for d.b.h. class. Trees showing excessive roughness were excluded from the sample groups.

---

[3]"Standard Grading Rules--1965" published by Western Wood Products Association, 700 Yeon Building, Portland, Oregon 97204.

[4]These characteristics are described on p. 6.

Within each of the seven characteristics classes and the control sample, trees were selected for four 3-inch d.b.h. classes: 7-9, 10-12, 13-15, and 16-18 inches. A maximum of four trees was planned for each diameter class, but four of the 32 sample groups could not be filled. Each of the 119 trees selected was scaled by a Forest Service scaler in the mill yard; this produced a net scale totaling 10,290 board feet, Scribner Decimal C.

For milling, logs were sorted into characteristics classes, debarked, cut into nominal 8-foot lengths, and sawed by scrag mill and edger into 2 X 4 studs. The yield of 2,321 2 X 4 studs totaled 11,400 board feet.

The study lumber was machine-stacked and dried on the kiln schedule of the cooperating mill. This schedule was reported to dry the lumber to a final moisture content of 10 to 13 percent, with gradients averaging 1 percent after equalization and conditioning. The lumber was surfaced and later graded by certified WWPA lumber graders, leaving ends untrimmed to preserve color identifications. After the grading, an individual piece tally was made and essential data, including tree characteristics class, d.b.h. class, board size, and lumber grade were recorded.

RESULTS AND DISCUSSION

In 2 X 4 stud recovery, grade yield decreased as the more severe tree characteristics were introduced (table 1). Forked stems markedly reduced recovery. Logs in this class yielded the greatest volumes of unmerchantable studs and the smallest amount of Standard and Construction grade lumber. Since we were unable to fill the allotted sample in the 16- to 18-inch diameter class of forked stems, total board-foot recovery was low. Even so, we believe the data here generally indicate actual distribution of grade recovery from forked trees.

Table 1 also shows that the larger trees yielded proportionately more high-grade lumber than the smaller trees. Most of the studs (61-percent of total recovery) from the larger trees were graded either Construction or Standard. The cumulative percent of grade recovery, including pieces classed as unmerchantable, is shown in table 2.

Table 1.--Stud yield in board-foot measure by diameter class, lumber grade, and tree characteristic

D.b.h. class (inches)	Lumber grade: Construction	Standard	Utility	Economy	Unmerchantable[1]	Total
			CONTROL			
7-9	107	21	16	5	5	154
10-12	185	53	32	53	5	328
13-15	282	69	32	59	21	463
16-18	367	105	53	164	42	731
TOTAL	941	248	133	281	73	1,676
			GENERAL SWEEP			
7-9	80	11	5	27	0	123
10-12	170	32	21	26	0	249
13-15	240	80	16	64	0	400
16-18	370	112	130	194	74	880
TOTAL	860	235	172	311	74	1,652
			SPIRAL GRAIN			
7-9	0	0	0	0	0	0
10-12	165	53	21	48	32	319
13-15	264	91	32	154	21	562
16-18	171	75	64	186	43	539
TOTAL	600	219	117	388	96	1,420
			SHORT BUTT CROOK			
7-9	75	42	5	5	5	132
10-12	59	27	27	53	11	177
13-15	245	69	85	128	53	580
16-18	123	27	21	120	27	318
TOTAL	502	165	138	306	96	1,207

D.b.h. class (inches)	Lumber grade: Construction	Standard	Utility	Economy	Unmerchantable[1]	Total
			ECCENTRIC PITH			
7-9	58	11	21	32	0	122
10-12	176	21	27	37	5	266
13-15	192	85	75	75	48	475
16-18	223	112	85	282	75	777
TOTAL	649	229	208	426	128	1,640
			STEM CROOK			
7-9	64	21	37	53	11	186
10-12	202	86	59	75	59	481
13-15	192	117	59	144	32	544
16-18	238	75	96	176	32	617
TOTAL	696	299	251	448	134	1,828
			FLUTED BUTTS			
7-9	32	21	16	43	21	133
10-12	96	32	59	59	11	257
13-15	218	75	48	147	37	525
16-18	245	133	96	229	69	772
TOTAL	591	261	219	478	138	1,687
			FORKED STEM			
7-9	27	27	21	37	27	139
10-12	48	75	48	64	21	256
13-15	165	64	64	197	91	581
16-18	64	16	53	59	64	256
TOTAL	304	182	186	357	203	1,232

Total merchantable, 11,400 board feet.
Total unmerchantable, 942 board feet.

[1]Material classified as "unmerchantable" failed to satisfy the requirements for Economy grade. Most of the pieces thus classified contained excessive warp, bow, crook, twist, and other natural defects.

Table 2.--Cumulative lumber yields as percentage of total by tree characteristics and lumber grades

Tree characteristic	Lumber grade: Construction	Standard and better	Utility and better	Economy and better	Unmerchantable
Control	56.1	70.9	78.8	95.6	4.4
General sweep	52.0	66.2	76.6	95.5	4.5
Spiral grain	42.2	57.7	65.9	93.2	6.8
Short butt crook	41.6	55.3	66.7	92.0	8.0
Eccentric pith	39.6	53.6	66.3	92.3	7.7
Stem crook	38.1	54.5	68.2	92.7	7.3
Fluted butts	35.0	50.5	63.5	91.8	8.2
Forked stem	24.7	39.5	54.6	83.6	16.4

CONCLUSIONS

Four conclusions were drawn from this study of 2 X 4 stud yield from lodgepole pine:

1. In small trees, lumber yields by grades are affected most by eccentric pith, stem crook, fluted butts, and forkedness.

2. In all diameter classes, forked trees yield relatively low percentages of easily marketable studs.

3. Stem crook seems to have about the same effect on all sizes of trees.

4. The larger trees yield proportionately more high-grade studs than smaller trees.

SUMMARY

This study showed that acceptable yields of marketable grades of 2 X 4 studs can be recovered from lodgepole pine trees with varied characteristics. Trees with severe defects, particularly forked stems, yield relatively small volumes of the better grades of studs.

DESCRIPTION OF TREE CHARACTERISTICS

Short butt crook is the maximum deviation from a right cylinder in the section of the tree from ground line to a height of 10 feet. It is measured at the point of maximum deviation.

Stem crook is a deviation from the vertical axis in one or more successive 8-foot lengths both above and below which the stem is straight. Maximum deviation is measured between the two points where deviation from the general vertical axis starts and stops.

General sweep is a continuous curvature extending throughout one-half or more of a tree-length log in contrast to the abrupt deviation in butt or in stem crooks that usually involve shorter sections of the tree length. The curvature of sweep is measured over the lengths of two successive 8-foot logs at the point of maximum deviation.

Forked stem is a divided trunk resulting from injury at the growing tip that divided the trunk into two stems, or from simultaneous growth of a lateral branch along the leader that caused multiple forking along certain stems. Bark inclusions at the position of forking is a potential result. The height from the stump cut to the beginning of the fork is recorded.

A tree-length log was classified as having eccentric pith if any radius from the pith to the bark on the stump was greater than two-thirds of the diameter extended at 180° from that radius. To minimize confounding of eccentric pith with such characteristics as butt crook, stem crook, and sweep, they were excluded from this class.

Fluted butt is a tree characteristic in which a cross section of the stump shows a scalloped periphery extending one-half or more of the length of an 8-foot log in a swelled butt. The severity of fluted butts is determined from the cross section of the butt end of the tree.

Spiral grain is a deviation in grain, steeper than 1 inch in 12, from a parallel to the vertical axis of the tree.

NOTE: The Control sample of logs in this study was free from the tree characteristics described above. Only logs well below the specified limits for crook, pith eccentricity, butt fluting, and spiral grain were included in the Control sample.

Figure 1.--A. Even after defective sections are cut out of forked trees, lumber yields of high-grade studs are relatively low. B. Stem crook is fairly common in lodgepole pine. Badly crooked sections must be trimmed off before straight 2 X 4's can be manufactured. C. Spiral-grained trees can yield many straight studs if manufacturing processes are good.

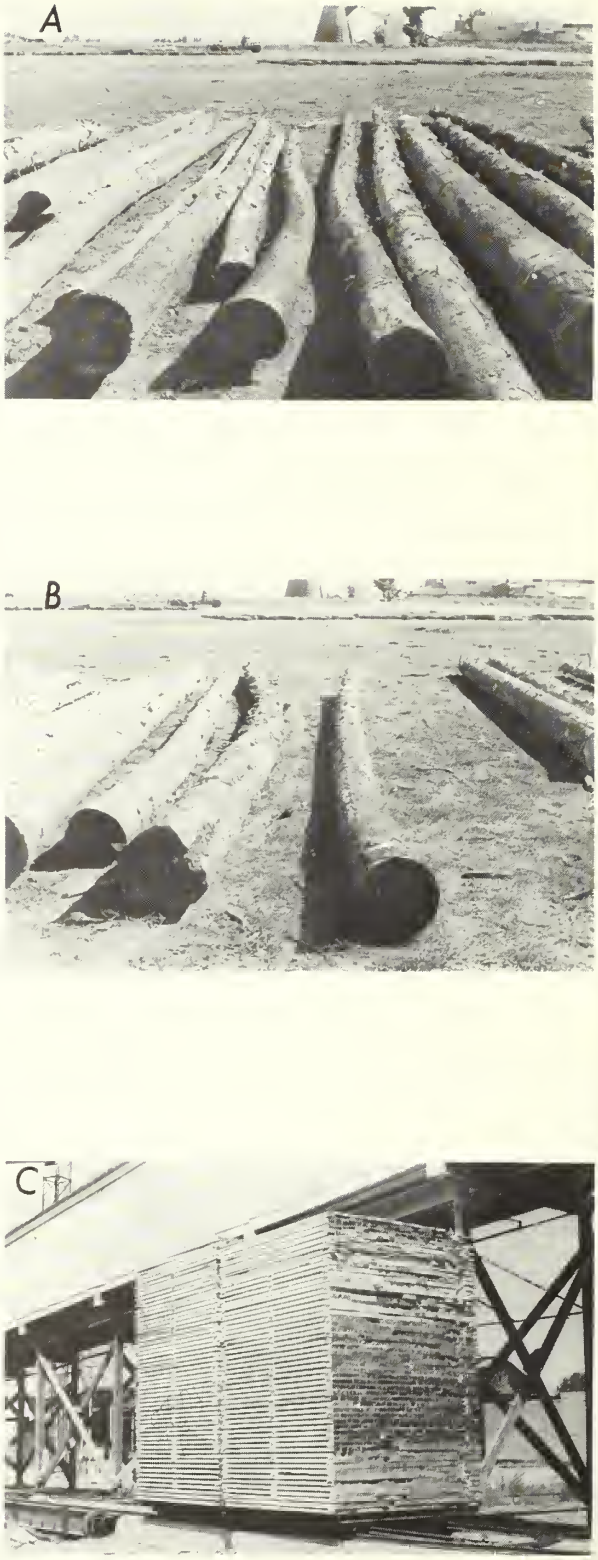


Figure 2.--A. Short, 8-foot logs can be cut from stem-crooked trees if the crook is not too severe. B. General sweep has little effect on lumber yields when short, 8-foot logs are desired. C. Green-study lumber was carefully stacked and dried in a modern forced-air dry kiln.

Research Note

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

U.S. Forest Service
Research Note INT-64

1967

INSOLATION LIMITS INITIAL ESTABLISHMENT OF WESTERN LARCH SEEDLINGS

Raymond C. Shearer[1]

ABSTRACT

During a 2-year study of spot seeding of western larch (Larix occidentalis Nutt.), insolation was the chief cause of death. Effects of insolation were most pronounced on seedlings less than 3 months old on west- and south-facing slopes. Insolation was most severe in early summer if soils were dry. Soil surface temperatures of 130° F. and higher consistently killed seedlings. Successful seeding practices are noted and recommended.

PURPOSE AND SCOPE

Insolation frequently alters the number and distribution of first-year larch seedlings. This paper describes the effects of insolation on young larch seedlings, as influenced by seed pretreatment, screening, aspect, and sowing time. Other agents kill many seedlings, but these are not discussed in this paper.

LITERATURE REVIEW

Insolation has been known to be lethal to seedlings for a half-century

Insolation was first recognized as a factor capable of inflicting heavy first-year seedling losses in the United States when Hartley (1916) described its effect on tree seedlings in the sandy nursery soils of Nebraska. Subsequent studies have shown that high temperature at the soil surface limits the establishment of many species of young seedlings, particularly on the exposed sites of this country (Bates and Roeser 1924; Toumey and Neethling 1924; Haig 1936; Isaac 1938; Smith 1940; and Shearer 1960).

[1]Associate Silviculturist, headquartered at Forestry Sciences Laboratory, Missoula, Montana, which is maintained in cooperation with the University of Montana.

The seriousness of losses due to heat in western larch was first shown by Haig (1936). He identified insolation as the most important agent causing mortality to first-year larch seedlings in full sunlight and in partial shade. No losses from heat occurred under complete shade.

Insolation first produces stem lesions near the ground surface; constriction of the stem follows; then death

The first indication of damage from heat is a water-soaked appearance at the hypocotyl base (Smith and Silen 1963) or a light-colored lesion usually forming on the south or west side of the stem at or near the ground (Toumey and Neethling 1924). Following lesion formation, a shallow constriction forms around the hypocotyl at ground level (Smith and Silen 1963). As the constriction deepens, young seedlings (Douglas-fir up to 4 weeks old) bend to the ground, but older seedlings with good secondary xylem development usually remain erect. Smith and Silen (1963) found constrictions were fatal to Douglas-fir seedlings only when cells collapsed across the pericycle and into the differentiating vascular cambium.

IMPORTANCE OF ENVIRONMENT

Summer climate in western larch range is conducive to insolation of seedlings

Throughout the range of western larch in the northern Rocky Mountains, the summers are characterized by clear, hot, and sunny days; low humidity; high evaporation; and scant rainfall. This region receives 70 to 80 percent of the possible sunshine from June through August (U.S. Dep. Agr. 1941). Because of the large number of clear, hot days, the upper soil dries rapidly and high temperatures are common at the soil surface. Young vegetation, including newly emerged larch seedlings, is especially vulnerable to severe damage or death by the intense heat concentrated at the air-soil interface.

We studied insolation on a cutover area at 4,000 feet elevation where soil was gravelly loam

A recently cutover area on a lower mountain slope on the Coram Experimental Forest was selected for the installation of a spring spot seeding in 1960. Only three-fourths of the germination occurred that year. The remaining one-fourth was delayed until the spring of 1961.

The seed spots ranged in elevation from 3,950 to 4,350 feet. Western larch, Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), Engelmann spruce (*Picea engelmannii* Parry), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) formerly occupied the area.

The soil was derived from glacial till and was classified as Waits gravelly loam. An average of 31.3 inches of precipitation falls yearly in nearly equal amounts of rain and snow.[2] July and August are usually hot and dry.

[2] Weather records (1948-1963) from Hungry Horse Dam, Mont., 5 miles from the study area.

IDENTIFYING HEAT-KILLED SEEDLINGS

Insolation and damping-off usually show clearly differentiated symptoms

Heat damage to seedlings was identified on the plots by applying the following criteria to differentiate between losses caused by insolation and damping-off fungi:

Insolation	Damping-off
1. Small white lesions on stems frequently distinct near the soil surface.	1. No stem lesions.
2. Constriction of stem at and slightly above the soil surface, but not below.	2. Constriction of stem is limited to soil surface and below.
3. No decay in root below the constriction, and root color is normal light-green to pinkish.	3. Root usually spongy below the constriction and white in color.

FACTORS INFLUENCING INSOLATION

ASPECT

Insolation is most severe on south and west aspects

Severity of insolation was influenced more strongly by the exposure of the seedbed to direct radiation than by any other factor studied. Seedling losses caused by lethal temperatures were most severe on south and west aspects (table 1) where the soil was exposed to direct radiation for long periods. In 1960, six times more seedlings were killed by heat on southerly and westerly aspects than on northerly slopes. These losses increased sharply on all aspects in 1961, because there were more clear, hot days in June 1961 than in June 1960; these hot days caused rapid drying of surface soil and subsequent soil heating. It was the second driest June on record in western Montana, with high maximum temperatures and much sunshine (table 2). In 1961 maximum losses on north slopes due to insolation occurred when the sun was near its summer solstice. The number of seedling deaths caused by insolation on north slopes after July 1 was the same for both years. Seedlings began to die on south- and west-facing slopes 2 weeks sooner than on north-facing slopes, because the soils dried sooner on the more exposed sites.

SCREENING

Screens reduced surface soil temperatures and reduced mortality from insolation in 1961

In addition to providing varying degrees of protection from animals, screens reduce surface soil temperature significantly (Fowells and Arnold 1939; Krauch 1938). Screening did not reduce mortality from excessive heat in 1960, but did reduce the losses in 1961 (table 3).

SEED PRETREATMENT AND SOWING DATE

Seed pretreatment and sowing date influenced germination but not losses from heat

Although both seed pretreatment and date of sowing strongly influenced the germination behavior of the seeds, neither influenced the number of seedlings killed by high surface temperatures. At any inspection date, seedlings 1 week old were no more susceptible to heat injury than those 6 weeks old. In addition, the 1960 losses decreased as the season advanced even though high surface temperatures (138° F.) continued throughout most of August (table 4). Apparently, the seedlings surviving at the end of 1960 grew on more favorable microsites.

RESULTS

Insolation was very destructive in both experiment seasons

Insolation was the chief cause of first-year seedling losses (table 1). The number of seedlings killed by heat was second only to the number killed by drought in 1960. In 1961, insolation was the main cause of mortality. Only newly germinated seedlings were killed by high surface temperatures. Heat damage to the young seedlings started after the surface soil dried and the temperatures at the soil-air interface became extremely hot (possibly between 138° F. and 150° F.).

Measured maximum soil surface temperatures in early July were 150° F.

Temperatures at the air-soil interface.--The symptomatic identification of heat-caused mortality was supported in 1960 by temperature data collected from plots adjacent to the seed spots. Soil surface temperatures were measured on these plots with pellets[3] designed to melt at 113°, 125°, 138°, and 150° F. Maximum surface temperatures often exceeded 150° F. in early July and frequently surpassed 138° F. throughout July. The percent of 138° F. pellets melted and the maximum air temperature during the same period were significantly correlated (table 4). This relationship was not true for the 150° F. pellets. Instead, the area at the air-soil interface that reached or exceeded 150° F. steadily decreased from early July through mid-August, even though the highest air temperatures for the year occurred between the middle and the end of July.

Clear, hot, dry days in late June and early July cause heavy loss from insolation

Table 4 (150° F. column) shows that maximum surface temperatures may occur while the sun is at or near its summer solstice. In years with many clear, dry days--especially in June and in early July, as was true in 1961--insolation causes greater losses than in years with less sunshine, as in 1960. These losses began and peaked 3 weeks earlier in 1961 than in 1960 (fig. 1). About 57 percent of this mortality occurred between June 19 and 29, 1961, whereas the first heat-caused losses in 1960 were not identified until July 7.

[3] Tempils sold by Tempil Corporation, New York, N. Y. Use of trade name is solely for convenience in identification and does not constitute endorsement by the U.S. Forest Service.

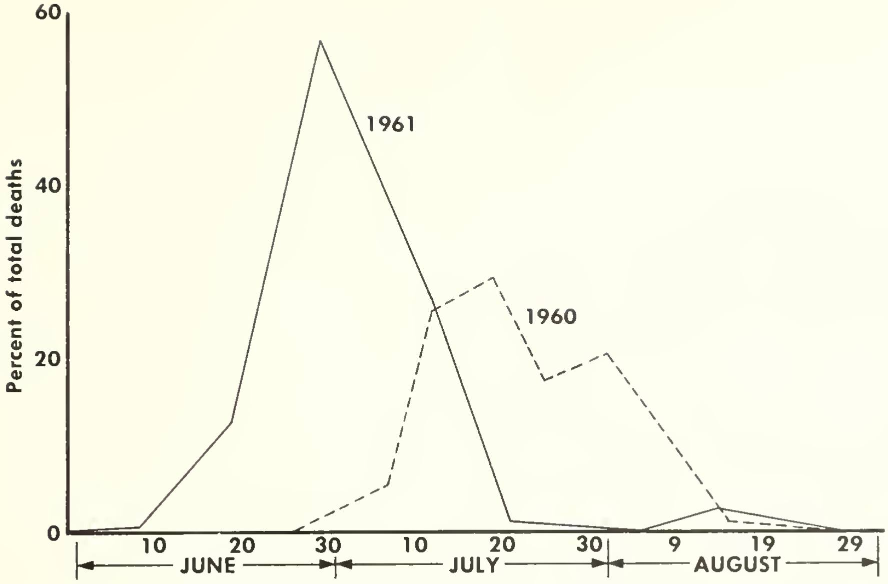


Figure 1.--Insolation-caused mortality by date.

DISCUSSION

Larch seedlings exposed to high temperatures are susceptible to injury or death

Temperatures greater than 138° F. are common at the soil-air interface during July and August on bare seedbeds. Temperatures are more likely to reach 138° F. on south and west aspects than on north slopes. Larch seedlings exposed to this temperature are very susceptible to injury or death. Bates and Roeser (1924) found that sustained temperatures of 130° F. could seriously injure seedlings when the soils were drying. Baker (1929) concluded that 1- to 3-month-old seedlings were readily killed by temperatures of 130° F. but survived at temperatures a few degrees lower. Lorenz (1939) showed that the cortical parenchyma cells of several conifers and hardwoods were killed within 30 minutes at temperatures from 134° F. to 138° F. and within 1 minute at 149° F. to 156° F.

Susceptibility to heat injury seems not to be correlated with age

This study, like several others (Lorenz 1939; Shirley 1936; Smith and Silen 1963), failed to show a correlation between seedling age and susceptibility to heat injury. Smith and Silen (1963) concluded if heat tolerance is greater in older seedlings, it has a physiological rather than an anatomical basis.

From a laboratory test, Shirley (1936) concluded that the cooling effect of transpiration probably provided the greatest protection to young seedlings against excess heat in dry air.

RECOMMENDATIONS

Limit seeding of larch to north aspects

Direct seeding of western larch cannot be recommended on south and west aspects because of the extreme risk of losing most of the seedlings to high surface soil temperatures. Larch stands sometimes are established on such slopes following fires or other disturbance, but foresters cannot afford to distribute millions of seeds per acre, as nature often does, to insure successful regeneration. Seeding should be limited to northerly slopes unless insolation can be reduced by some means on the exposed aspects.

SUMMARY

The installation of an experiment in spot seeding western larch on the Coram Experimental Forest in 1960 showed that insolation killed many new seedlings during their first growing season. Nearly three-fourths of the germination occurred in 1960, but the remainder held over until 1961. Other observations from this experiment were:

1. Lethal temperatures caused the greatest loss of larch seedlings.

2. Direction of slope was the most important factor related to insolation-caused deaths. Many more seedlings on south and west aspects were killed than seedlings growing on north slopes.

3. Seed pretreatment and sowing time had no significant influence on the number of young western larch seedlings killed by insolation.

4. Protection by screens did not reduce mortality in 1960; but in 1961, a very hot, dry year, the wire mesh screens reduced the number of deaths.

5. Insolation-caused losses started after the surface soil dried. These deaths began on north-facing slopes 1 to 2 weeks later than on south or west aspects.

6. Mortality caused by insolation occurred within 3 months after germination.

7. Direct seeding should be practiced only on north-facing slopes, where losses from heat are least.

Table 1.--Mortality of first-year western larch seedlings, by year, aspect, and agent

Year	Aspect	Cause of mortality						
		Insolation	Drought	Fungi	Frost	Clipping	Other	Living
		Percent						
1960	North	6	36	8	13	6	5	26
	South and west	37	30	13	5	6	4	5
	Average	30	32	12	7	6	4	9
1961	North	24	12	16	5	1	5	37
	South and west	47	16	23	4	4	4	2
	Average	42	15	21	4	4	4	10

Table 2.--Possible sunshine measured at Missoula, Montana,[1] for June, July, and August in 1960 and 1961

Year	June	July	August
	Percent		
1960	67	91	59
1961	83	85	74
Average (1950-1962)	60	81	72

[1]Although Missoula is about 100 airline miles from the study area, it is believed the percent of sunshine is very nearly equal at both locations.

Table 3.--Mortality of first-year western larch seedlings, caused by insolation, as influenced by degree of shading and by year of germination[1]

Year	Degree of shading		
	Open	3 mesh per inch	1 mesh per inch
	Percent		
1960	36	37	36
1961	70	56	51

[1]Seedlings surviving earlier losses.

Table 4.--Influence of date and maximum air temperature on the temperature at the soil-air interface, in 1960

Date	Maximum air temperature	Temperature pellets melted	
		138° F. pellet[1]	150° F. pellet
	Degrees F.	Percent	
July 6-12	90	69	42
July 13-21	100	97	34
July 22-29	89	27	25
July 30-August 3	94	60	21
August 4-14	87	17	4
August 15-18	80	0	0

[1]Highly significant correlation (r = .92) between maximum air temperature and percent of 138° F. pellets melted.

LITERATURE CITED

Baker, Frederick S.
1929. Effect of excessively high temperatures on coniferous reproduction. J. Forest. 27: 949-975.

Bates, Carlos G., and Jacob Roeser, Jr.
1924. Relative resistance of tree seedlings to excessive heat. U.S. Dep. Agr. Dep. Bull. 1263, 16 p

Fowells, H. A., and R. K. Arnold.
1939. Hardware cloth seed spot screens reduce high surface soil temperatures. J. Forest. 37: 821-8

Haig, Irvine T.
1936. Factors controlling initial establishment of western white pine and associated species. Yale Ur School of Forest. Bull. 41, 149 pp.

Hartley, Carl.
1916. Non-parasitic stem lesions on seedlings. Phytopathology 6: 308-309.

Isaac, Leo A.
1938. Factors affecting establishment of Douglas-fir seedlings. U.S. Dep. Agr. Circ. 486, 45 pp.

Krauch, H.
1938. Does screening of seed spots do more than protect the spots against rodents and birds? U.S. F est Serv., Southwestern Forest and Range Exp. Sta. Res. Note 49, 4 pp.

Lorenz, Ralph W.
1939. High temperature tolerance of forest trees. Univ. Minn. Agr. Exp. Sta. Tech. Bull. 141, 25 p

Shearer, Raymond C.
1960. First-year mortality of coniferous seedlings in the western larch--Douglas-fir type. Mont. A Sci. Proc. 20: 18-19.

Shirley, Hardy L.
1936. Lethal high temperatures for conifers and the cooling effect of transpiration. J. Agr. Res. 5 239-258.

Smith, Frank H., and Roy R. Silen.
1963. Anatomy of heat-damaged Douglas-fir seedlings. Forest Sci. 9: 15-32.

Smith, Lloyd F.
1940. Factors controlling the early development and survival of eastern white pine (Pinus strobus L. central New England. Ecol. Monogr. 10: 373-420.

Toumey, James W., and Ernest J. Neethling.
1924. Insolation a factor in the natural regeneration of certain conifers. Yale Univ. School of Fores Bull. 11, 63 pp.

U.S. Department of Agriculture.
1941. Climate and man. Agr. Yearbook, 1248 pp.

AFPS, Ogden, Utah

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-65 1967

MARKET TRENDS FOR WESTERN WHITE PINE

Robert E. Benson and Larry L. Kirkwold[1]

ABSTRACT

Western white pine has historically been one of the most important timber species harvested in the Rocky Mountain area. This study summarizes changes that have taken place during the past 4 decades in western white pine lumber production, lumber prices, and major manufacturing uses.

Western white pine (Pinus monticola Dougl.) historically has been one of the most economically important timber species harvested in the Rocky Mountain area. Since 1920, it has comprised about 15 percent of the lumber produced in the nine Mountain States and was one of the mainstays in the development of the timber industry, using the forest resources in the white pine region of northern Idaho and adjacent areas.[2] Because of its desirable qualities, white pine has generally been regarded as a premium lumber species and has consistently brought higher prices than other species in the Mountain States. The establishment of blister rust control units and intensive efforts to control this disease reflect the importance of white pine in past timber management programs.

During the past 2 decades, there has been an apparent shift in the role of white pine in the timber industry of the area and in its position in national markets. Total lumber production in the Mountain States has increased rapidly with the expanded harvest of species that had been only lightly utilized in the past. White pine production has remained relatively stable because there was little room for expanded output without overcutting. Average lumber prices of most Mountain States' species have increased in relation to white pine lumber prices.

---

[1]Benson is Marketing Analyst at the Forestry Sciences Laboratory in Missoula, Montana, which is maintained by the Forest Service in cooperation with the University of Montana.

Kirkwold was formerly Associate Marketing Analyst with the Station. He is now with the Weyerhaeuser Company, located in Tacoma, Washington.

[2]Matthews, Donald N., and S. Blair Hutchison. Development of a blister rust control policy for the National Forests in the Inland Empire. U.S. Forest Serv., Northern Rocky Mountain Forest and Range Exp. Sta., Sta. Pap. 16. 1948.

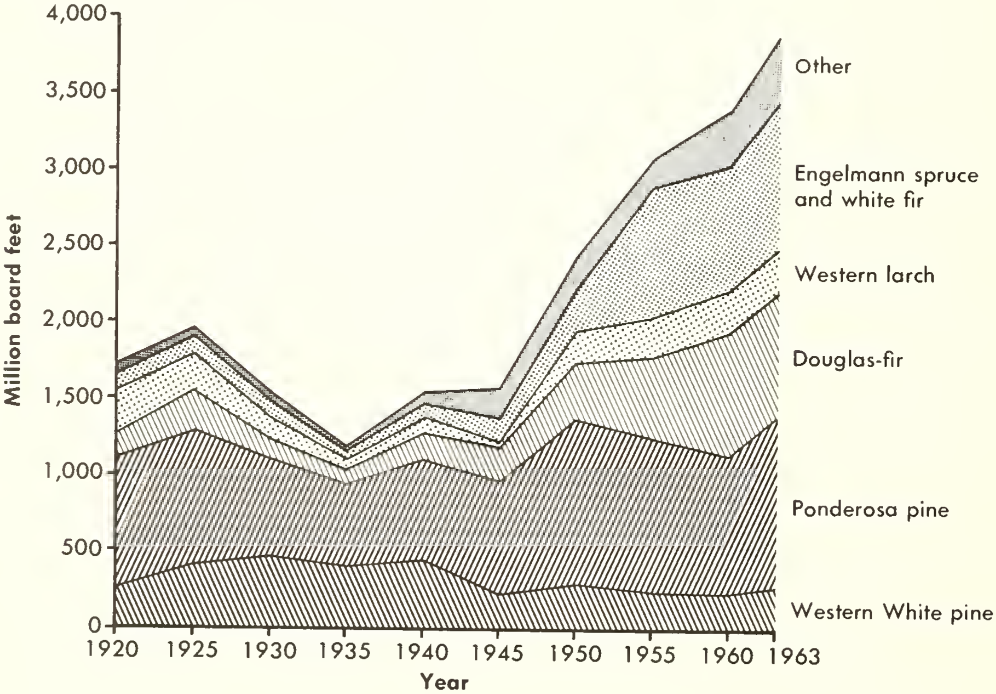
Changes such as these are important in resource planning since management objectives should reflect not only growth potential of the land and management costs but also the demands of wood markets.

Projecting future wood needs is at best a speculative business, and anticipating future demands for white pine alone is beyond the scope of this study. However, this report summarizes information on past production, price, and uses of white pine that may provide some useful insight for those involved in management planning.

PRODUCTION AND PRICES OF LUMBER

Production of white pine lumber in the Mountain States began in the 1890's and was at its peak during the 1930's when annual production averaged over 350 million board feet (fig. 1). During the depressed markets of the 1930's when production from other species declined sharply, white pine production remained relatively stable and, along with ponderosa pine, was the mainstay of the area's lumber industry.

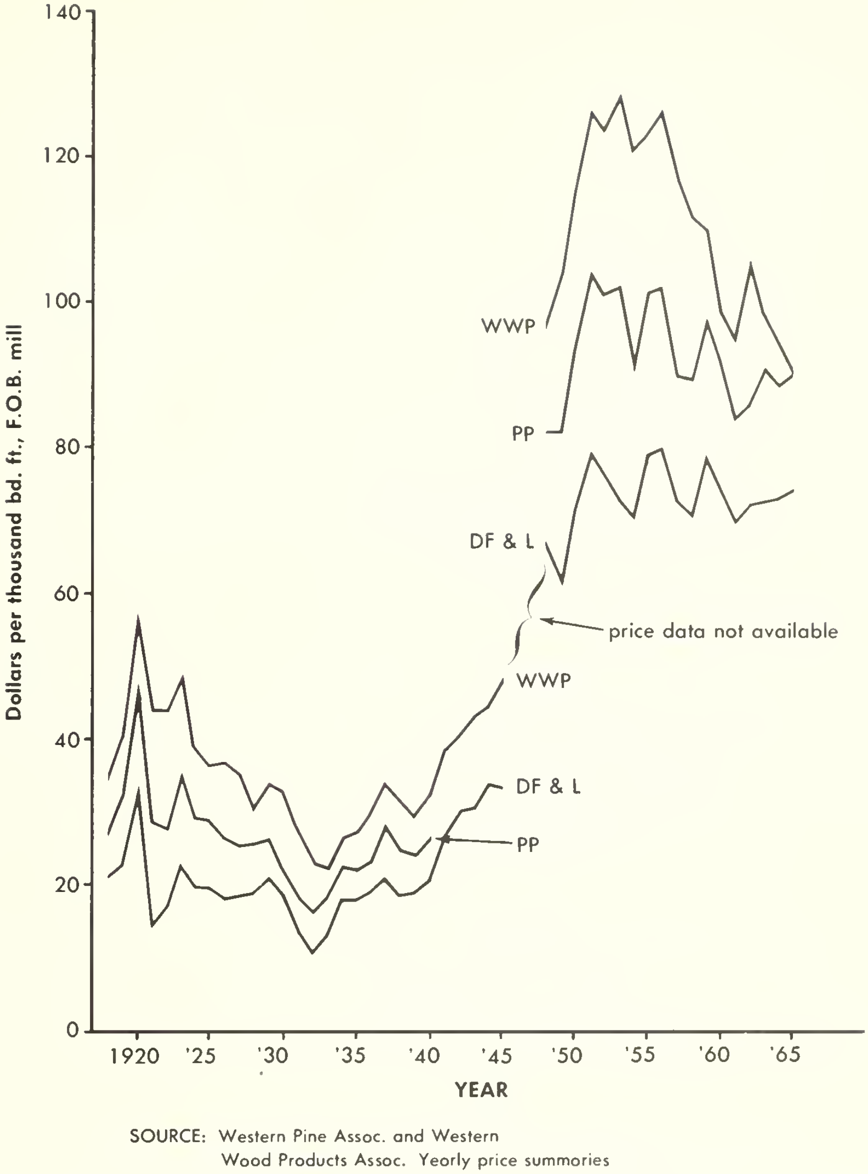
Following World War II, the building boom increased the demand for lumber and expanded the utilization of Douglas-fir, western larch, Engelmann spruce, white fir, and other species in the Mountain States. Total lumber production in the area climbed to 3.8 billion board feet in 1963. During this postwar period, white pine lumber production stabilized at about 250 million board feet per year.



Source: USDA 1948. Lumber production in the United States 1799 - 1946
Henry B. Steer. USDA Misc. Pub. 669
U.S. Dep. Commerce. Lumber Production and Mill Stocks
Ser. M13G-09 and M24T.

Figure 1.--Lumber production in the Mountain States (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, South Dakota, Utah, and Wyoming), 1920-1963.

Figure 2.--Average wholesale lumber prices for western white pine, ponderosa pine, and Douglas-fir and larch, 1918-1965.



The average wholesale price of white pine lumber has historically been higher than prices of the other principal lumber species of the region. It has maintained this position despite fluctuations from a low of $22/M bd.ft. in 1933 to a peak of $129/M bd.ft. in 1953 and a subsequent decline to $91/M bd.ft. in 1965 (fig. 2).

When lumber prices declined during the depression years, white pine prices held up better than those of other species, and the relative margin between prices of white pine and other species increased. Since the depression, however, the prices of other species have generally improved relative to white pine, particularly during the past decade (table 1).

This change in price relationships along with the increase in production of other species has reduced white pine's share of the total wholesale value of lumber produced in the Mountain States. In 1963, white pine accounted for about 10 percent of the value, compared to 42 percent in 1930 and 37 percent in 1940 (table 2).

Table 1.--Index of average wholesale lumber price for principal Mountain States' species, white pine = 100

Species	Period				
	1920-1929	1930-1939	1940-1949[1]	1950-1959	1960-1965
	Average index for period				
Western white pine	100	100	100	100	100
Ponderosa pine	74	78	82	81	92
Douglas-fir and western larch	50	60	69	63	75
Engelmann spruce	64	67	79	69	75
White fir	52	48	59	56	62

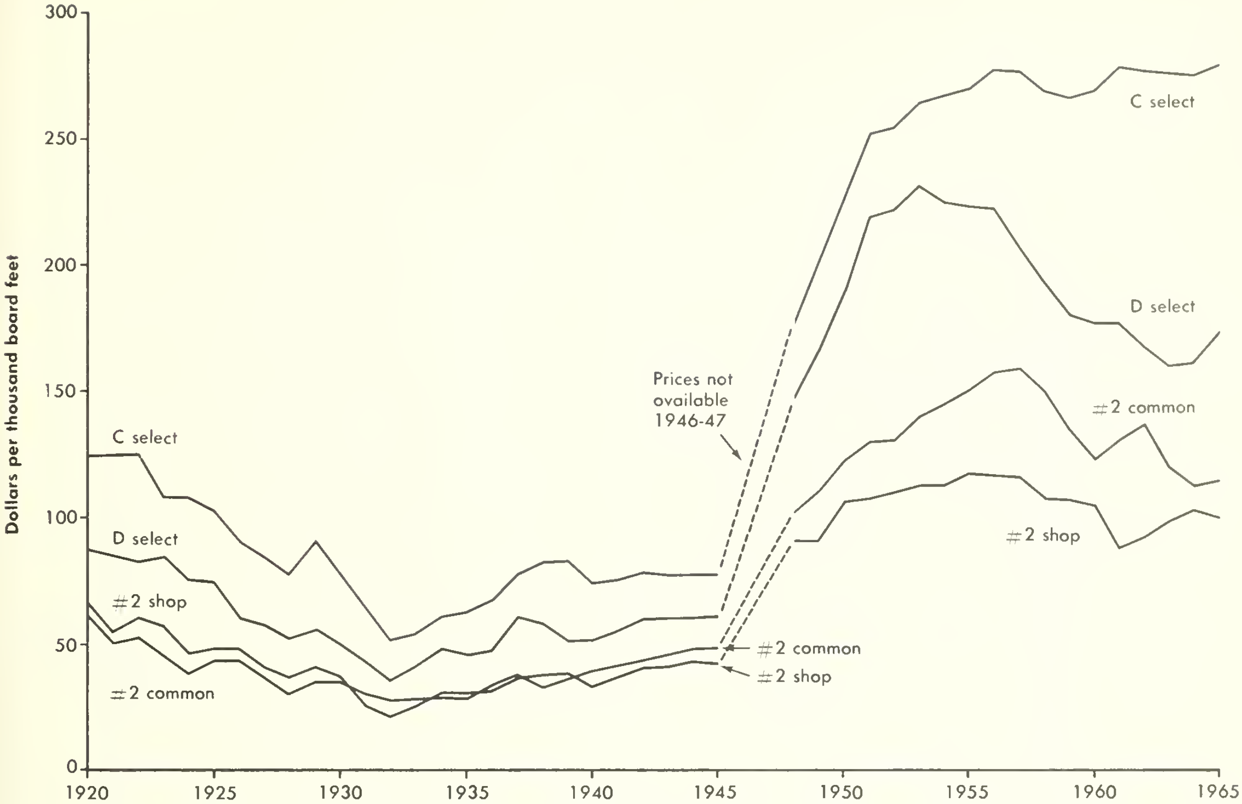
[1] Price data are not complete for this period. Index is based on averages for following years; ponderosa pine and white fir--1940, 1948, and 1949; Engelmann spruce and Douglas-fir and western larch, 1940-1945, 1948, and 1949.

Price trends for the various grades of white pine lumber have differed. Prior to the mid-1950's, there was a fairly constant relation between prices of the different grades of white pine lumber, but since the mid-1950's there have been divergent price trends. Price of C select has remained fairly level and prices of shop grades have declined only slightly. However, the prices of D select and common grades have dropped substantially. Figure 3 shows price trends for some representative grades of white pine lumber.

The price relation between white pine and ponderosa pine, the other principal board lumber species of the Mountain States, also has varied by grade. In select and shop grades, the prices of the two species are virtually the same (fig. 4). In common grades, white pine has retained substantial price margins (fig. 5).

Table 2.--Distribution of total wholesale value of lumber produced from principal Mountain States' species

Species	Year					
	1920	1930	1940	1950	1960	1963
	Percent					
Western white pine	20	42	37	17	10	10
Ponderosa pine	54	39	45	52	34	37
Douglas-fir and western larch	19	14	14	22	33	30
Engelmann spruce	3	2	3	5	11	10
White fir	4	3	1	4	12	13
Total, principal species	100	100	100	100	100	100



Source: Western Pine and Western Wood Products Assoc. Yearly price summaries

Figure 3.--Wholesale price of western white pine lumber selected grades, 1920-1965.

TRENDS IN WOOD USE

In 1960, manufacturing industries used about one-third of the total western white pine lumber production and almost 60 percent of the higher value grades of white pine lumber: select, shop, and #1 and #3 common (table 3).

Within this market, there have been some significant shifts in white pine use. Most notable is the sharp decline in manufacture of wood matches. The wood match industry used over 70 million board feet of western white pine in 1933, or over half of the western white pine used by manufacturing industries that year. By 1960, only about one-half million board feet of white pine was used by the wood match industry (fig. 6). This market, which was almost exclusively served by western white pine, has virtually disappeared.

Since the decline of the wood match market, the millwork industry has been the biggest manufacturing outlet for white pine lumber; in 1960, nearly half the white pine used in manufacturing went to the millwork industry. White pine used in boxes and crates has declined, but its use for patterns, furniture, and other industries has gradually increased since 1933.

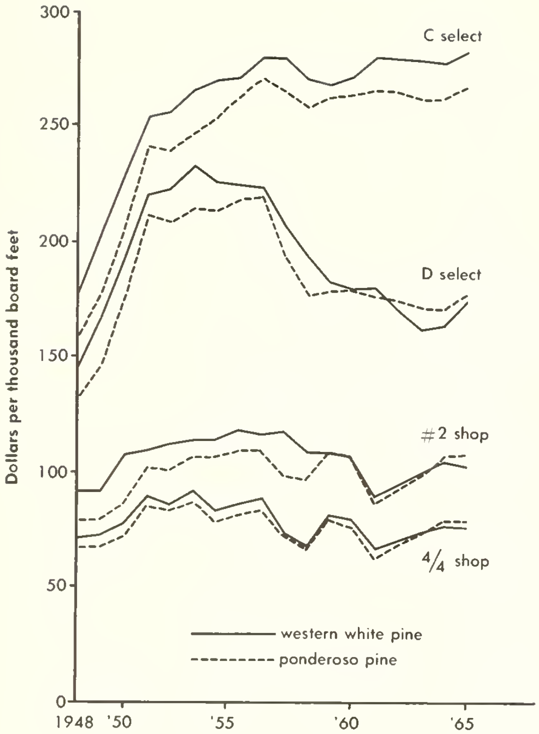


Figure 4. --Wholesale lumber price of western white pine and ponderosa pine, select and shop grades, 1948-1965.

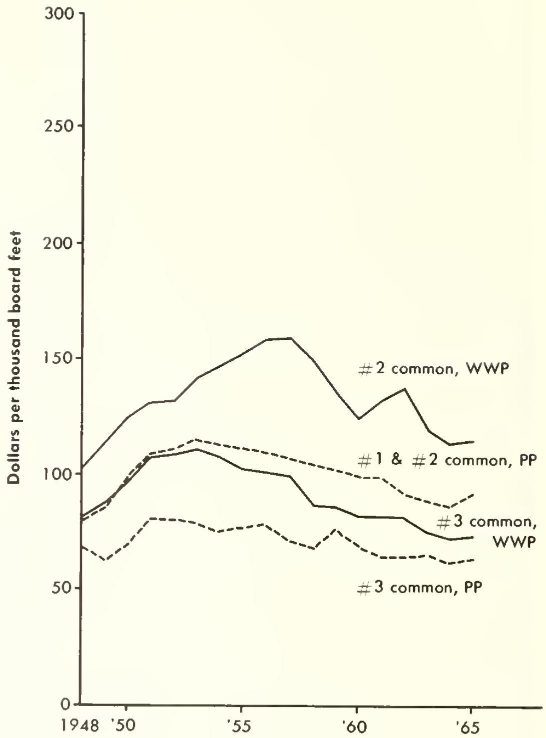


Figure 5. --Wholesale lumber price of western white pine and ponderosa pine, common grades, 1948-1965.

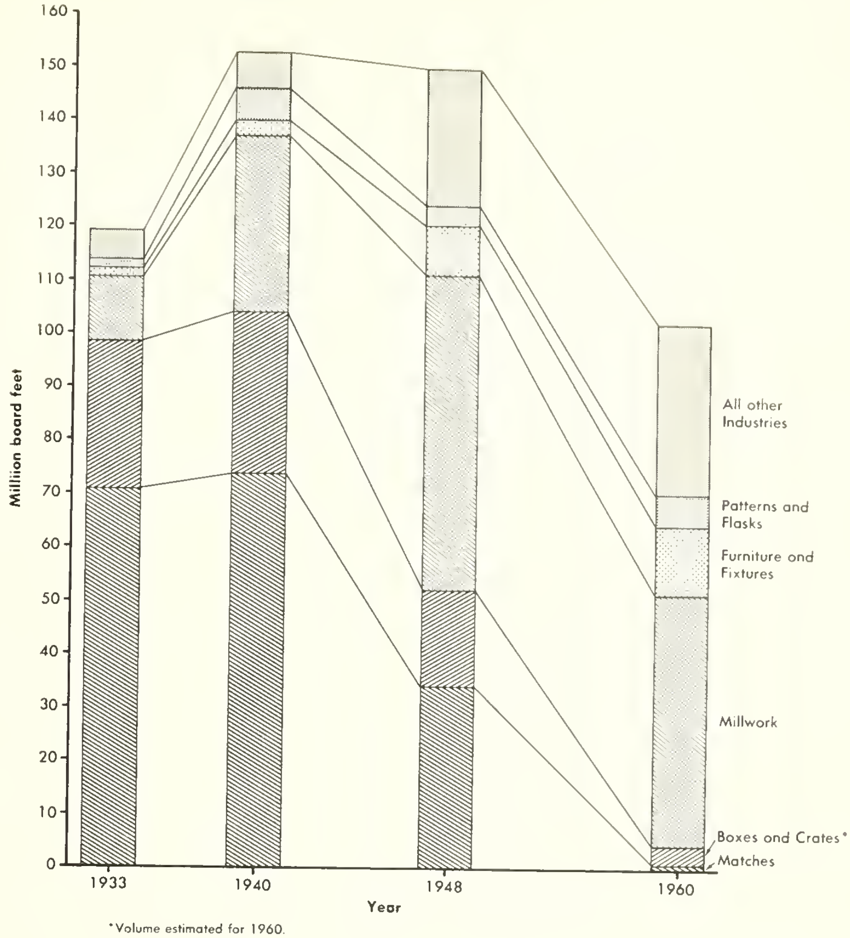
White pine accounts for a relatively small proportion of the total softwood lumber used by manufacturing industries. About 10 percent of all softwood lumber used in patterns and flasks is white pine. In millwork and furniture manufacturing, about 7 percent of the total softwood lumber used is white pine.

The decline in use of boards for sheathing, subflooring, and roofing in light construction constitutes the loss of another volume market for several species, including white pine. Plywood has made major inroads into this market, which was formerly an outlet for lower grades of soft pine lumber.[3]

White pine plywood is a relatively minor item in national markets. Nevertheless, about 111 million square feet (3/8-inch basis) of white pine plywood was produced in the Mountain States in 1965. This was about 15 percent of the total plywood production in these States.[4]

[3] Phelps, Robert B. Wood products used in single family houses inspected by the Federal Housing Administration 1959 and 1962. U.S. Dep. Agr., Forest Serv., Statist. Bull. 366. 1966.
[4] Forest Industries. 35th Annu. Plywood Rev. (93): 1. 1966.

Figure 6.--Western white pine used in manufacturing industries.



CONCLUSIONS

Past use patterns and price relations among species and grades have only a limited relevance to wood markets that are now evolving. The shift in industrial uses for white pine noted in this study and development of new uses, such as white pine plywood, are examples of changing wood markets. It is likely that further substitution among species, as well as new developments of both wood and nonwood materials will be the major factors that determine the amount used and the price paid for any individual species in the future.

The market trends presented in this report provide one measure of white pine's role in wood markets. Another important consideration is the technological suitability of white pine and other species in specific end uses. The critical limits of wood performance and costs of substitution among species are not always fully reflected in overall market data such as production, price, and use trends.

Table 3.--Western white pine lumber used in manufacturing industries in 1960, by grade

Grade	Western white pine lumber		
	Used in manufacuring industries	Other uses	Total production
	Million board feet		
Select and Shop	18	25	43
#1 and #2 Common	57	33	90
#3 Common and lower	27	172	199
Total	102	230	332

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-66 1967

EFFECT OF PARTIAL CUTTING IN OVERMATURE LODGEPOLE PINE

Charles R. Hatch[1]

ABSTRACT

Reports 11-year observations of a partially cut 120- to 160-year-old lodgepole pine stand in western Montana. Heavy mortality following partial cutting caused a yearly net growth rate of -53 cubic feet per acre. Mortality remained relatively uniform on an annual basis over the 11-year period. Adequate regeneration followed cutting although the overstory rapidly infected the stand with dwarfmistletoe.

Partial cutting of lodgepole pine (Pinus contorta Dougl.) stands was generally accepted and widely practiced in Montana prior to 1946. With the advent of large-scale pulpwood cutting in old-growth stands, selective forms of cutting were gradually abandoned in favor of clearcutting. Whether clearcutting or selective cutting was a more suitable practice from the standpoint of regeneration and ultimate yield became highly conjectural. Because of uncertainty, a series of observational plots was established[2] in a partially cut stand in western Montana. The objectives were (1) to measure growth response and mortality of the residual stand, and (2) to determine the amount of natural regeneration following partial cutting.

---

[1]Assistant Silviculturist, who is headquartered in Bozeman, Montana, at the Forestry Sciences Laboratory, which is maintained in cooperation with the Montana State University.

[2]R. K. LeBarron established the study; K. N. Boe collected 6th-year measurement data; David Tackle collected 11th-year measurement data and initiated data analysis. All were research foresters formerly assigned to this study.

Eleven-year records now attest the soundness of early decisions to clearcut overmature, heavily mistletoed lodgepole pine stands. This paper supports other observational and experimental evidence weighing heavily against partial cutting in low vigor, old-growth stands (Alexander 1954, 1966; Blyth 1957; Hornibrook 1940; LeBarron 1952; Mowat 1949).

STUDY AREA

The study area is located on north- and south-facing exposures at an elevation of 6,600 feet in the Moser Creek drainage of the Gallatin National Forest, Montana. Slope gradients were gentle to moderate--10 to 20 percent--on terrain of average site quality. The plots were established in a pure, overmature stand of lodgepole pine 120 to 160 years of age. Prior to cutting in 1947, the stand had a volume of 4,370 cubic feet per acre.

The vigor of the stand averaged C-minus, according to Taylor's (1937, 1939) tree classification system. The stand had suffered heavy mortality during the past 20 years and nearly 100 percent of the trees and saplings were infected with dwarfmistletoe (*Arceuthobium americanum*). However, the dwarfmistletoe had not caused excessive brooming.

Before logging, reproduction averaged 2,920 trees per acre on the north slope and 160 trees per acre on the south slope. More than 50 percent of the seedlings and saplings were lodgepole pine. Engelmann spruce (*Picea engelmanni*), Douglas-fir (*Pseudotsuga menziesii*), limber pine (*Pinus flexilis*), and subalpine fir (*Abies lasiocarpa*) were also present. Principal understory vegetation on the area included grouse whortleberry (*Vaccinium scoparium*), snowberry (*Symphoricarpos* spp.), pinegrass (*Calamagrostis rubescens*), arnica (*Arnica* spp.), and beadlily (*Clintonia* spp.)

METHODS

Five circular, tenth-acre plots were installed on each aspect. On each plot, all trees 0.5-inch d.b.h. and larger were recorded by location, species, 1-inch diameter class, and amount of dwarfmistletoe infection. Dwarfmistletoe infection was subjectively placed into one of four classes: none, light, medium, or heavy. Lodgepole pine 5 inches d.b.h. and larger were rated using Taylor's tree classification system, and volumes were computed for all species. Harvested trees, trees destroyed by logging, and residual trees were located and tallied immediately following logging. The plots were remeasured in 1953 and 1957.

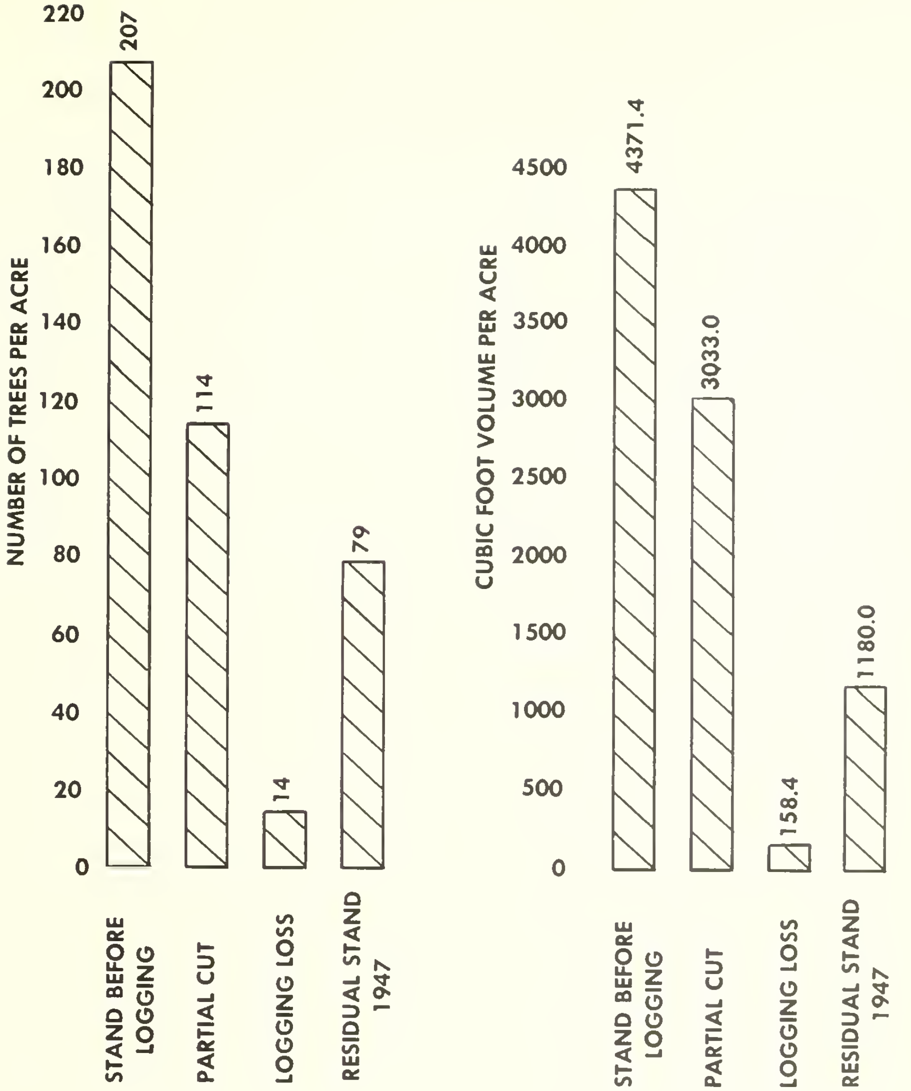


Figure 1.--Changes in the stand following partial cutting in 1947, all trees 5 inches d.b.h. and larger.

Thrifty trees and trees of the size and quality for transmission line poles were marked as "leave" trees. The selective cut removed 69 percent of the volume. Logging losses reduced the volume by an additional 4 percent. Figure 1 shows the changes that occurred in the stand during partial cutting in 1947.

Regeneration density and stocking were measured at each plot by using a transect of 10 square-milacre quadrats. On each quadrat, all trees less than 0.5-inch d.b.h. were recorded by species and 1-foot height class. Reproduction quadrat recordings were made before logging in 1947 and during plot remeasurement in 1953 and 1957.

<u>RESULTS</u>

Periodic annual gross increment was only 14 cubic feet per acre during the first measurement period. Ingrowth contributed nearly one-quarter of the gross growth. Gross growth did not increase substantially during the last 5 years[3] of measurement (table 1). Mortality was four times greater than gross increment during the 11-year period. By 1957, the residual stand volume had been reduced 49 percent (fig. 2).

Wind was responsible for over one-half of the mortality. Periodic annual mortality during both measurement periods was approximately the same (table 2).

Six years after logging, the north and south slopes were 78 and 34 percent stocked, respectively. Stocking increased slowly and at about the same rate during the second measurement period (table 3).

---

[3]The period of time was 4 years, but nearly five growing seasons were covered--May 1953 to August 1957.

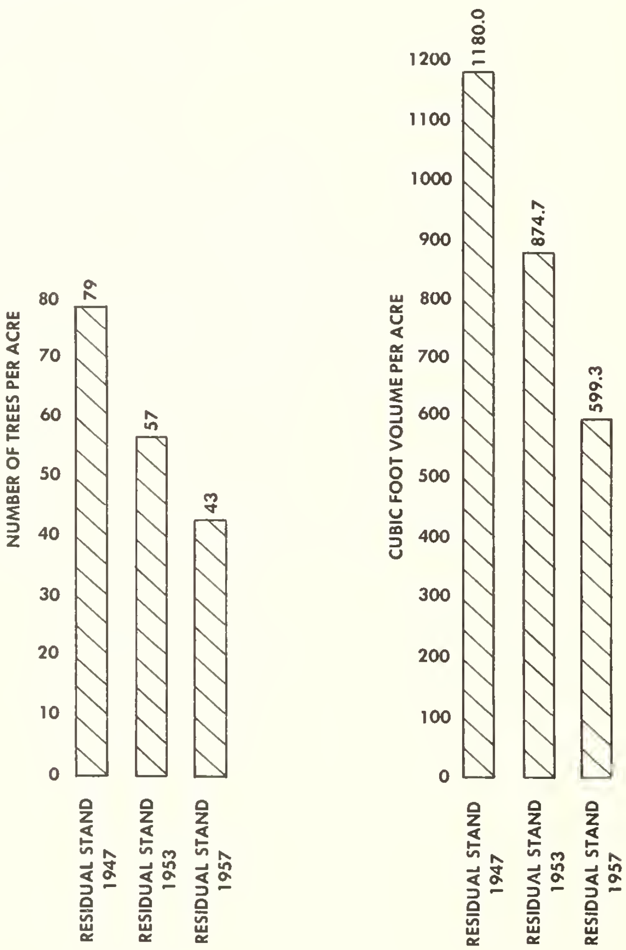


Figure 2.--Growth of residual stand following partial cutting in 1947, all trees 5 inches d.b.h. and larger.

Table 1.--Periodic annual increment and mortality, all trees 5 inches d.b.h. and larger

Period	Ingrowth	Gross increment	Mortality	Net increment
	Number of trees per acre			
First 6 years	1	1	5	-4
Last 5 years	1	1	4	-3
11-year period	1	1	4	-3
	Cubic foot volume per acre			
First 6 years	3.2	14.2	65.1	-50.9
Last 5 years	3.9	19.5	74.6	-55.1
11-year period	3.5	16.6	69.4	-52.8

Table 2.--Periodic annual mortality by cause, all trees 5 inches d.b.h. and larger

Cause	First 6 years 1947-1953	Last 5 years 1953-1957	11-year period 1947-1957
	Number of trees		
Wind	3	2	2
Other[1]	2	2	2
Total	5	4	4
	Cubic foot volume		
Wind	47.0	33.9	41.0
Other	18.1	40.7	28.4
Total	65.1	74.6	69.4

[1] Includes mortality due to trespass cutting and unknown factors.

Table 3.--Seedling distribution and density by aspect

spect	Seedling distribution						Seedling density	
	1947[1]		1953		1957		1957	
	LPP[2]	All species[3]	LPP	All species	LPP	All species	LPP	All species
	Percent stocked milacre quadrats						No. of trees/acre	
N rth	50	70	68	78	74	84	4,240	5,100
S th	8	12	30	34	38	42	560	660

[1] Prior to logging.
[2] Lodgepole pine.
[3] Lodgepole pine, Engelmann spruce, Douglas-fir, limber pine, and subalpine fir.

DISCUSSION AND CONCLUSIONS

Too often, partial cutting was used as an interim practice, with clearcutting as a final objective. As market conditions changed, the terminal cut was never made. A heavily diseased stand of jumbled age classes was the final result. The final stand lacked adequate volume and value to justify an economical cut.

A severe partial cut, 69 percent of the original stand's cubic foot volume, contributed to the heavy loss of residual stand volume through mortality. Much of the unclassified mortality could probably be related to root damage and similar injury sustained during logging. After partial cutting, the stand went steadily downhill. Losses remained relatively uniform on an annual basis for the 11-year period.

Since no measure of stocking or ground scarification was made immediately following logging, stocking and seedbed conditions at that time are unknown. Advanced regeneration in even-aged old-growth lodgepole pine stands is seldom abundant or disease-free. If such stands are infected with dwarfmistletoe, clearcutting is desirable and should include the advanced regeneration.

Increased regeneration was noted on the area after 6 years. Although the north slope was overstocked and the south slope had the minimum allowable stocking in 1957, the diseased residual stand had begun to infect the reproduction with dwarfmistletoe.

Observations of the overmature stand indicated that a partial cut should not have been made. Chances for a successful partial cut are determined largely by the vigor of the residual stand, by the site, and by accessibility and market opportunities. Partial cutting in the lodgepole pine type should be made only for cultural benefits, such as thinning or sanitation.

LITERATURE CITED

Alexander, R. R.
1954. Mortality following partial cutting in virgin lodgepole pine. U.S. Forest Serv., Rocky Mountain Forest & Range Exp. Sta., Sta. Pap. 16, 9 pp.

_____ 1966. Harvest cutting old-growth lodgepole pine in the central Rocky Mountains. J. Forest. 64: 113-116, illus.

Blyth, A. W.
1957. The effect of partial cutting in even-aged lodgepole pine stands. Can. Dep. N. Aff. & Nat. Resources, Forest. Br., Forest Res. Div. Tech. Note 61, 14 pp., illus.

Hornibrook, E. M.
1940. A preliminary yield table for selectively cut lodgepole pine stands. J. Forest. 38: 641-643.

LeBarron, R. K.
1952. Silvicultural practices for lodgepole pine in Montana. U.S. Forest Serv., Northern Rocky Mountain Forest & Range Exp. Sta., Sta. Pap. 33, 19 pp., illus.

Mowat, E. L.
1949. Preliminary guides for the management of lodgepole pine in Oregon and Washington. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta. Res. Note 54, 10 pp., illus.

Taylor, R. F.
1937. A tree classification for lodgepole pine in Colorado and Wyoming. J. Forest. 35: 868-875, illus.

_____ 1939. The application of a tree classification in marking lodgepole pine for selection cutting. J. Forest. 37: 777-782, illus.

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-67

1967

THE INFLUENCE OF GROWTH MEDIA, TEMPERATURES, AND LIGHT INTENSITIES ON ASPEN ROOT AND TOP GROWTH

Gerald F. Gifford [1]

ABSTRACT

Root and top growth of aspen cuttings in three soils (sand, loam, and clay) were studied in a controlled environmental chamber. The cuttings were exposed to two light intensities (2,000 ft.-c. and 600 ft.-c.) for 50 days at each of three temperatures (10°, 18°, and 27° C.). Root growth in loam soil was favored when plants were grown at 18° C. but at 27° C. the top growth was erratic and root growth was small. At all temperatures and light intensities, the plants growing in sand and clay produced smaller yields of roots and less top growth than did those growing in loam. Light intensity significantly influenced root growth only in loam soil at 18° C. Top growth was not significantly influenced by light intensity at all three temperatures.

Little is known of the effect of selected environmental factors upon growth of aspen (Populus tremuloides Michx.) under controlled conditions. Farmer[2] found that a reduction of light intensity from 1,700 to 500 ft.-c. was accompanied by a significant reduction in height growth of aspen cuttings at 24.4° C. day--21.6° C. night. At 21.1° C. day--18.9° C. night, no significant difference in height growth attributable to light intensity was observed. Results were interpreted in terms of the relation between photosynthetic accumulation and respiratory loss of energy as affected by temperature and light.

---

[1] Assistant Professor in the Department of Range Science, College of Natural Resources, Utah State University. This work was done by the author while he was a graduate student at the University and was supported in part by the Intermountain Forest and Range Experiment Station.

The author expresses appreciation for assistance in preparing this manuscript to Dr. Norbert V. DeByle of the Station's staff, who is headquartered in Logan at the Forestry Sciences Laboratory, which is maintained by the Forest Service, U.S. Department of Agriculture, in cooperation with the University.

[2] Farmer, R. E., Jr. Effect of light intensity on growth of Populus tremuloides cuttings under two temperature regimes. Ecology 44: 409-411. 1963.

Stoeckeler[3] discovered the highest site index in aspen growing on soils with a silt plus clay content of approximately 50 percent while doing an extensive site evaluation of Minnesota and Wisconsin aspen stands. He attributed this to a combination of greater nutrient content in the finer textured soils and the favorable moisture conditions prevailing at this 50-percent content of fine particles.

MATERIALS AND METHODS

During late August and early September, aspen roots were dug from the upper $1\frac{1}{2}$ feet of soil under a single clone near Logan, Utah. A brief description of the site has been published.[4] All roots removed were cut into 3-inch lengths and replanted the same day. Each root cutting was allowed to develop a sprout, and the sprout a small adventitious root system. Greenhouse temperatures were maintained at approximately 19±5° C. during this period.

The sprouts then were selected at random and transplanted into the clay, sand, and loam soils (table 1 describes these soils). Each flat of soil contained one plant which was still attached to its approximately 1-inch diameter root stock. Three plants were grown under low light intensity and four plants under high light intensity in each soil for 50 days at temperatures of 10°, 18°, and 27° C. Light intensities of 2,000 ft.-c. and 600 ft.-c. were applied at each temperature. The diurnal cycle consisted of 15 hours illumination and 9 hours darkness. The controlled environmental chamber had a light source in the ceiling consisting of forty-four 8-foot-long G.E. power-groove fluorescent tubes and twenty-eight 50-watt Ken-Rad 300-volt incandescent lamps.[5] Maximum light output at 3 feet below the source was 2,000 ft.-c.

Plants were well watered, but the soil was not saturated. Soil moisture availability was always near 0.3 bar of suction at the bottom of the flat and from 0.6 bar to 5 bars of suction near the surface at the time of watering.

Table 1.--Properties of the soils used in this study

Soil class	Sand	Silt	Clay	Exch. K.	Avail. P	Total N
	Percent			Meq./100 gms.	Lbs. P_2O_5/A.	Percent
Sand	100	0	0	0.04	3	0.005
Clay	7	35	58	.50	43	.092
Loam	48	30	22	1.36	390	.363

[3]Stoeckeler, J. H. Soil factors affecting the growth of quaking aspen forests in the Lake States. Univ. Minn. Agr. Exp. Sta. Tech. Bull. 233, 48 pp., illus. 1960.

[4]Gifford, G. F. Aspen root studies on three sites in Northern Utah. Amer. Midl. Natur. 75: 132-141. 1966.

[5]Trade names as used herein are solely for identification and do not imply endorsement by the U.S. Forest Service.

RESULTS

Tests for significance were made among the various growth media and light intensities within each temperature regime. Statistical evaluation among temperature regimes was not possible.

Plants grown in loam at 18° C. under 2,000 ft.-c. produced more than three times the weight of roots as did those grown in sand and clay (table 2). Within the loam, the root yield from plants grown under 2,000 ft.-c. was significantly greater than that from plants under 600 ft.-c. illumination. There were no significant differences among growth media or light intensities at either 10° or 27° C.

Table 2.--Average root yield under selected environmental conditions [1]

(In grams)

Soil class	600 ft.-c.			2,000 ft.-c.		
	10° C.	18° C.	27° C.	10° C.	18° C.	27° C.
Sand	0.34	1.05	1.61	0.80	1.24	2.00
Clay	.36	.96	1.43	.44	1.14	1.22
Loam	.46	*1.80	1.46	1.22	**3.92	2.13

[1] Tabulated values are total root weights, which are the weights before placing plants in the growth chamber plus the growth of roots while in the chamber.

*Significantly different, at 5-percent probability level, from the growth in loam at 18° C. under 2,000 ft.-c.

**Significantly different, at 1-percent probability level, from the other values in the same column.

Plants grown in loam under 2,000 ft.-c. at both 18° and 27° C. produced significantly greater top growth than did plants grown in clay or sand at the same temperatures (table 3). Growth patterns of plants in the loam at 27° C. were erratic; new growth resulted from either or both the apical and lateral buds breaking dormancy. No significant differences in top growth occurred among growth media or light intensities at 10° C., or among light intensities at 18° or 27° C.

Table 3.--Average top growth under selected environmental conditions

(In grams)

Soil class	600 ft.-c.			2,000 ft.-c.		
	10° C.	18° C.	27° C.	10° C.	18° C.	27° C.
Sand	0.78	1.54	1.18	1.43	1.67	1.82
Clay	.44	1.45	1.22	.76	1.19	1.49
Loam	1.23	2.71	1.81	2.15	**4.16	**4.24

**Significantly different, at 1-percent probability level, from the other values in the same column.

DISCUSSION

The lack of significant top and root growth at 10° C., a marked increase in growth in loam soil at 18° C., and poor root growth combined with erratic top growth in loam soil at 27° C. provides some new insight into the physiology of aspen. Lack of growth and the insignificance of light intensity at 10° C. supports Farmer's conclusions[6] concerning a relationship, governed by temperature and light, between photosynthetic accumulation and respiratory loss of energy in aspen. According to this theory, enough photosynthesis occurred under the cool treatment (10° C.) so that growth under 600 ft.-c. was not limited by a shortage of available substrate. Instead, temperature probably was the limiting factor. In loam soil, from which adequate nutrients were available, the marked increase in growth at 18° C. and the significant difference in root growth among light intensities then reflects a condition of more favorable temperature but a greater respiration loss relative to photosynthate accumulation. Differences occurring among light intensities at this temperature reflect differing rates of photosynthesis. At 27° C., root growth was inhibited, perhaps due to destruction or alteration of certain root growth hormones or deactivation of the enzymes that utilize these hormones. At this high temperature, any photosynthate remaining after consumption by respiration was undoubtedly used in the erratic growth of tops.

Nutritional properties of the three media apparently influenced growth of aspen. A greater root growth occurred in those soils having high fertility levels of such elements as phosphorus, nitrogen, and potassium (tables 1 and 2). These results support Stoeckeler's site productivity work[7] under field conditions. It is well known that nutrient status of plants in general is extremely important to the rate of photosynthesis. The lack of nutrients probably explains the poor plant response in clay and sand to the favorable 18° C. temperature regime.

---

[6] See footnote 2.

[7] See footnote 3.

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

U.S. Forest Service
Research Note INT-68

1967

DOCUMENTATION OF LIGHTNING DISCHARGES AND RESULTANT FOREST FIRES

D. M. Fuquay, R. G. Baughman, A. R. Taylor, and R. G. Hawe[1]

ABSTRACT

Characteristics of lightning discharge and observed lightning effects were studied to determine whether a specific type of discharge causes ignition of forest fuels. Discharge characteristics, including return stroke type, magnitude, and duration, were recorded from the output of electric field change sensors at ground stations, while the discharges and their respective ground terminals (e.g., trees) were observed from a nearby aircraft. Seven discharges that caused forest fires were documented during four storms in 1965 and 1966. Evidence that all seven discharges had a long-continuing current phase supports the hypothesis that this type of discharge causes forest fires.

Lightning causes some 10,000 forest and range fires each year in the United States, but these fires probably represent only a small fraction of the total number of cloud-to-ground discharges occurring in that area during a year. The apparent inefficiency of lightning in igniting fires has given rise to the hypothesis that fires are caused by a particular type of discharge. McEachron and Hagenguth[2] proposed that discharges that ignite forest fuels usually have a long-continuing current phase. This

[1]Project Leader, Research Meteorologist, Research Forester, and Physical Scientist, respectively, stationed at Northern Forest Fire Laboratory, Missoula, Montana.

[2]McEachron, K. B., and J. H. Hagenguth. Effect of lightning on thin metal surfaces, AIEE Trans. 61: 559-564. 1942.

view resulted from work with laboratory sparks and from examination of lightning effects. Although the theory is widely accepted today,[3 4 5] the only known field corroboration to date was that reported by Norinder et al.,[6] who found that each of two discharges causing fire in Sweden had a long-continuing current phase. Using the methods described below, we have recently documented characteristics of seven lightning discharges that caused forest fires in western Montana.

METHODS

Discharge characteristics, including return stroke type, magnitude, luminosity, and duration, were recorded at ground-based recording stations. The sensors were fast and slow electric field change meters and a nondirectional luminosity device. The output of the sensors was recorded on a 7-channel tape recorder and retrieved later for analysis on a 14-channel oscillograph. The fast and slow field change sensors are identical, with the exception of the grid resistor in the electrometer stage. The grid resistor establishes the sensor time constant, which is 5 msec. for the fast antenna and 5 sec. for the slow antenna. The field change sensor circuit consists essentially of a flat-plate antenna, an electrometer stage, an emitter follower, and an amplifier. The output is directly proportional to the change in field at the antenna. The luminosity measuring system consists of a cone-shaped mirror and a parabolic mirror with an uncooled lead sulfide detector at the focal point. The detector is capacitor coupled to an output amplifier stage. The system has a 5-msec. time constant that corresponds to the fast field change meter.

The electric field change due to a lightning stroke measured at the surface of the earth can be given by the following equation[7] based on a simple positive dipole model:

$$\Delta E = 90 \frac{2Q_r H_r}{\left(D^2 + H_r^2\right)^{3/2}}$$

where ΔE is in volts/centimeter, Q_r is in coulombs, and H_r and D are in kilometers.

---

[3]Berger, K. Lightning research in Switzerland. Weather 2(3): 231-238. 1947.

[4]Malan, D. J. Physics of lightning, 176 pp., London: English Universities Press Limited. 1963.

[5]Loeb, Leonard B. The mechanisms of stepped and dart leaders in cloud-to-ground lightning strokes. J. Geophys. Res. 71(20): 4711-4721. 1966.

[6]Norinder, H., Knudsen, E., and Vollmer, B. Multiple strokes in lightning channels. In: Recent Advances in Atmospheric Electricity, pp. 525-542. New York: Pergamon Press. 1958.

[7]Brook, M. Kitagawa, N., and Workman, E. J. Quantitative study of strokes and continuing currents in lightning discharges to ground. J. Geophys. Res. 67(2): 649-659.

Here D is the horizontal distance from the field meter to the discharge, and H_r is the vertical height to the assumed center of Charge Q_r.

We measured the electric field change (ΔE) at two stations in 1965 and at four stations in 1966. The approximate horizontal distance (D) was found by aircraft observation. This information was then used to determine the electric charge (Q_r) and the vertical height to the charge center (H_r). To complete the record, the number of return strokes and duration were taken directly from the oscillograph readout for each recorded discharge.

We photographed the lightning discharges from a recording station with a 35-mm. camera operated by an electrostatic triggering device. This device is essentially a modified fast field change meter that produces a trigger pulse at the time of the discharge leader stroke. A counter is placed in front of the camera lens, providing a link between the photographs and the recorded field changes that correspond to them. Figure 1 is a composite of a lightning flash that started a forest fire on September 6, 1966, in western Montana (discharge number 4, table 1).

To document the effects of specific discharges upon forest fuels, we observed their ground terminals (usually trees) from a light aircraft flying near the storm. Upon seeing a nearby discharge, the aerial observer immediately transmitted a discharge identification number by radio to the lightning recording stations. His voice transmission was recorded on the same time-resolved magnetic tape that recorded the discharge, thus linking the aerial observation with its respective recording. The aircraft then circled in the immediate vicinity of the ground terminal and the observer attempted to locate it visually. If he was successful, he photographed the terminal (figure 2) and noted its location for subsequent on-the-ground study of lightning effects. Figure 3 shows the effects of the discharge characterized in figure 1.

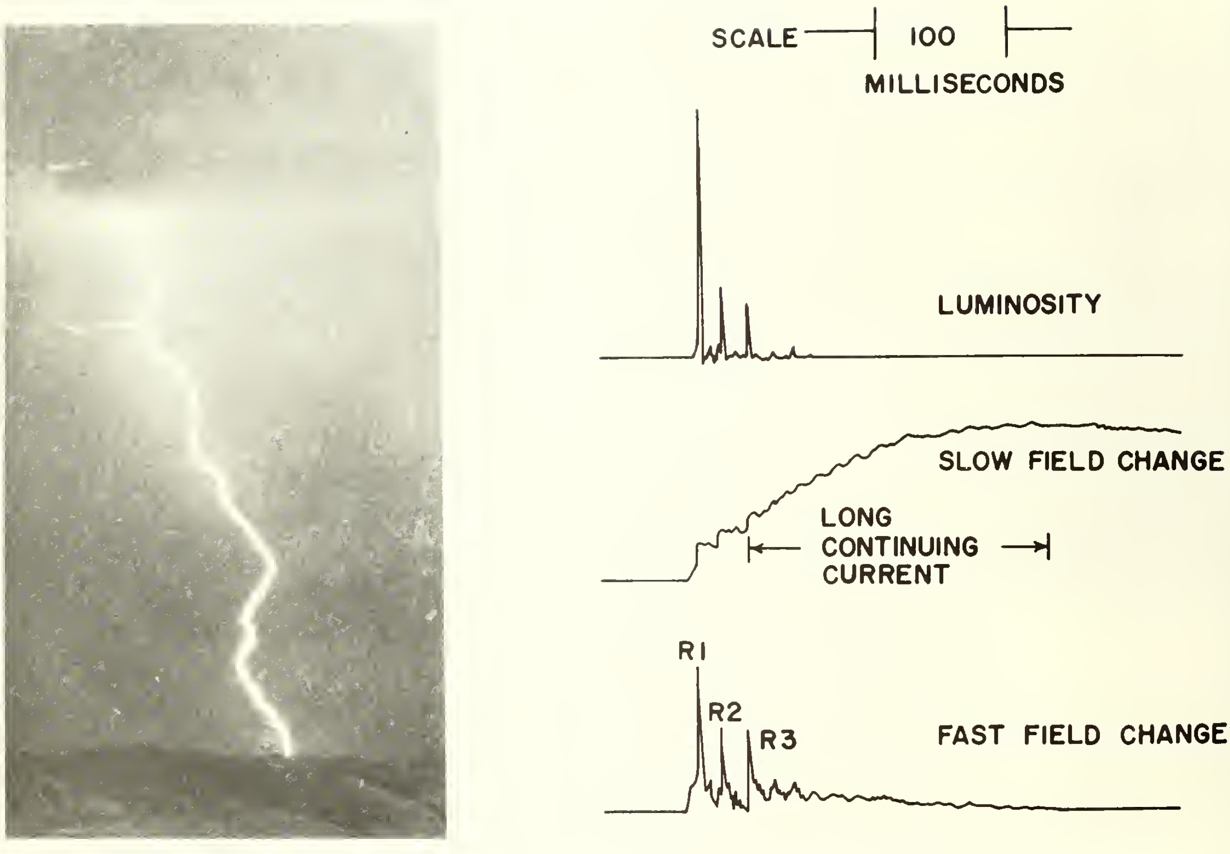


Figure 1.--Flash image, luminosity trace, and slow and fast field change traces of a discharge that caused a forest fire on September 6, 1966. Note the long-continuing current phase following the R3 stroke.

Figure 2. --Burning ground terminal photographed by aerial observer moments after lightning discharge was recorded at ground station 25 kilometers away.

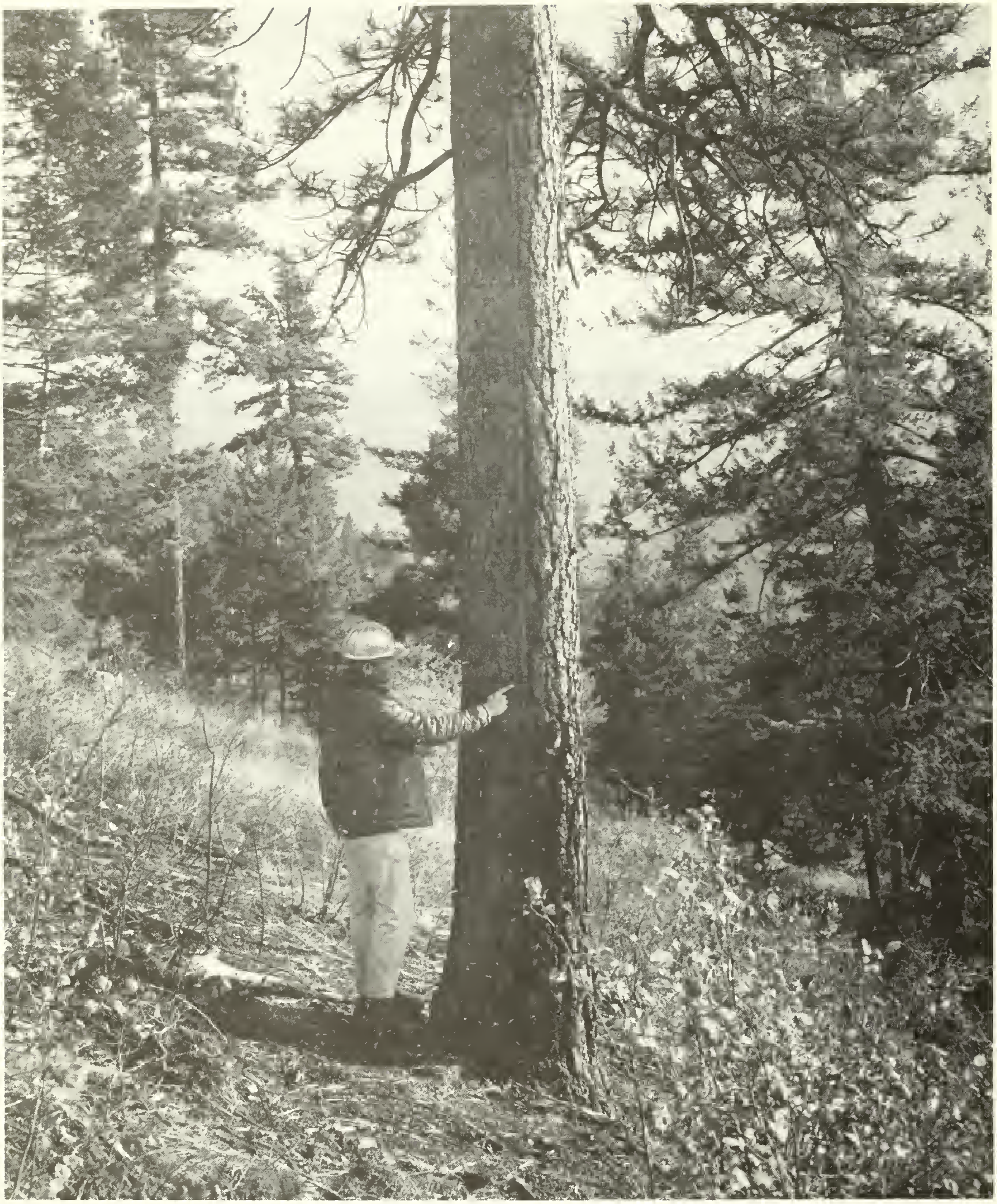


Figure 3.--Effects of the lightning discharge recorded in figure 1. Ponderosa pine shows narrow cambium depth scar and charring on lower 1.5 meters of bole. Creeping surface fire had final perimeter of 40 meters.

RESULTS

Using the procedures described above, the aerial observer attempted to identify the ground terminals of 30 discharges observed in four storms during 1965 and 1966. He was able to identify seven of them. All seven ground terminals exhibited fire, and all the fires were caused by discharges having a long-continuing current phase as illustrated in figure 1. Characteristics of the discharges are given in table 1. Average value of the continuing current was 158 amperes over an average interval of 203 msec. Of the 856 cloud-to-ground discharges recorded during 1965 and 1966, about half had a long-continuing current phase.

Three of the seven fires required suppression, and four were extinguished through natural causes. We examined fire and structural lightning effects at four of the fires and found that (1) each of the fires involved at least one lightning-struck tree; (2) one showed ignition evidence in crown foliage and upper stem only, two showed both upper stem and ground fuel ignition, and one (figure 3) showed ground fuel and lower stem ignition; and (3) structural nonfire lightning damage to the tree stems ranged from minor bark loss on the least damaged (figure 3) to splitting and ejection of wood slabs from the stem of the most severely damaged tree.

These data support the hypothesis that lightning fires are caused by discharges having long-continuing currents. With refinement of the techniques described above, we expect to document more discharges and their effects during 1967.

Table 1.--Characteristics of seven lightning discharges causing forest fires

Discharge no. and date	Total charge	Number of return strokes	Continuing current phase		
			Duration	Charge	Mean current
	Coul.		Msec.	Coul.	Amps.
1. 7/4/65	40	2	235	29	125
2. 7/14/66	48	3	282	44	156
3. 9/6/66	76	3	243	55	225
4. 9/6/66	93	3	205	61	298
5. 9/6/66	22	2	228	19	85
6. 9/6/66	26	9	40	1	25
7. 9/14/66	42	3	190	36	189

Acknowledgment.--This research was supported by the Atmospheric Sciences Section, National Science Foundation, NSF Grant No. GP-2617.

A/PS, Ogden

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-69

1967

ELEVEN-YEAR RESULTS OF STRIP-THINNING BY BULLDOZER IN THIRTY-YEAR-OLD LODGEPOLE PINE

by

James E. Lotan[1]

ABSTRACT

Bulldozer free thinning was tested as an inexpensive means of thinning noncommercial trees in young, dense lodgepole pine stands. Bulldozered strips were alternated with 2-, 6-, and 12-foot reserve strips in addition to a 25-foot control area in a 30-year-old lodgepole pine stand in western Montana. Diameter increment of trees on the 2-foot strips was double that of trees on the control area, but volume increment was only 20 percent of that of control areas. A decrease of height growth previously reported as due to thinning was not significant after 11 years.

INTRODUCTION

One of the most frustrating problems facing foresters interested in managing young lodgepole pine (Pinus contorta) in the Northern Rocky Mountain area is how to thin vast acreages of reproduction economically. Regrowth after harvest cuttings during the past 10 to 15 years has created a large thinning job. There is not much doubt of the need to thin, for commercial yields during the next rotation could be

[1]Associate Silviculturist, stationed at Forestry Sciences Laboratory, Bozeman, Montana, which is maintained in cooperation with Montana State University.

greatly increased with management. Wikstrom and Wellner[2] have estimated that present stands of lodgepole pine on medium sites have only 26 percent of the board-foot volume that might reasonably be expected if level of stocking were controlled. The question is how to achieve precommercial thinnings economically in these stands, where few trees express dominance.

In 1953, a study area in Montana was strip-thinned by bulldozer, and the results of examination 5 years later were reported by Tackle and Shearer.[3] This paper reports diameter and height growth 11 years after thinning.

METHODS

An abbreviated description of the study area and method of treatment is included here as a convenience to the reader.

At time of thinning (1953), the stand was 30-year-old, even-aged lodgepole pine located on a 40-percent slope on the Lolo National Forest in western Montana. Inventory before thinning showed 5,800 trees per acre, 79 percent of milacres stocked, average d.b.h. 1.5 inches, and stand composition 96 percent lodgepole pine and 4 percent larch. Total cubic-foot volume in 1953 was 1,541 ± 208 (95-percent level of probability).

A Caterpillar D-6 crawler tractor with a 12-foot blade was used for the thinning. Reserve strips 2, 6, and 12 feet wide were alternated with the 12-foot dozer swath which ran up and down the slope. Treatments removed 86, 67, and 50 percent of the volume for the 2-, 6-, and 12-foot-wide reserve strips, respectively, if we consider the dozer swath plus the reserve strip as the base area. Each reserve strip was replicated three times within the 8.8-acre experimental area; the replications of the series of reserve strips were separated by 25-foot-wide unthinned strips (two control strips in all).

Sample milacre plots were established along lines 1 chain apart crossing the slope and at right angles to the dozered strips. Control plots were located in the middle of the 25-foot unthinned area. All trees within the plots were tagged, and the following data were collected for each tree: species, crown class, d.b.h., total height, distance from edge of reserve strip. Trees were measured in 1958 and 1964, that is, 5 and 11 years after thinning.

---

[2] Wikstrom, J. H., and C. A. Wellner. The opportunity to thin and prune in the Northern Rocky Mountain and Intermountain regions. U.S. Forest Serv., Intermountain Forest & Range Exp. Sta. Res. Pap. 61, 14 pp., illus. 1961.

[3] Tackle, David, and R. C. Shearer. Strip-thinning by bulldozer in a young lodgepole pine stand. Mont. Acad. Sci. Proc. 19: 142-148. 1959.

RESULTS

Trends in diameter growth that existed at the 5-year examination continued through the 11-year examination (table 1). Trees on the 2-foot-wide reserve strips showed greater responses to thinning than those on the wider strips. Significant 5-year differences in height growth disappeared, except that combined height growth for dominant and codominant trees was greater than combined height growth for intermediate and suppressed trees.

Diameter.--The combined diameter growth of dominant and codominant trees on the 2-foot reserve strips during the first 5 years after thinning was approximately 1.5 times that of trees on the control area. The combined response for intermediate and suppressed trees on these strips was five times that of trees on the control area (table 1). This response has been maintained through the second measurement period. Diameter increment of trees on the 2-foot strips during the 11-year period was about twice that of trees on the control plots.

Eleven-year diameter growth of trees on the 2-foot reserve strips was significantly greater than that of trees on wider strips insofar as intermediate and suppressed trees were concerned, but results for dominants and codominants were not as clear cut. Dominant and codominant trees on 2-foot strips did no better than those on the 12-foot strips, but trees on both these strips were significantly different from trees on the control area. Significant differences in diameter growth between trees on control plots and trees on all other reserve strips, which might have been expected from early trends, did not appear after 11 years.

Table 1.--Average diameter and height growth of lodgepole pine 5 and 11 years after thinning, by reserve strip width

Strip	Diameter growth: Dominants and codominants		Diameter growth: Intermediates and suppressed		Height growth: Dominants and codominants		Height growth: Intermediates and suppressed	
	5 yr.	11 yr.	5 yr.	11 yr.	5 yr.	11 yr.	5 yr.	11 yr.
Reserve:	Inches				Feet			
2 ft.	0.50*	1.19*	0.21*	0.39*	1.9*	6.4	1.2	2.7
6 ft.	0.36	0.60	0.13	0.08	1.8*	8.0	1.1	2.4
12 ft.	0.34	0.94*	0.14	0.31	3.2	7.0	1.4	3.0
Control	0.33	0.64	0.04	0.20	4.1	6.7	0.9	3.1

* Means significantly different from control (5-percent level of probability).

Height.--Height growth of combined dominant and codominant trees was significantly greater than that of combined intermediate and suppressed trees within a thinning treatment. However, within crown classes, differences between trees on control plots and trees on other strips were not significant. The decrease of height growth inversely related to strip width after 5 years, as reported by Tackle and Shearer, was not significant after 11 years.

Distance from strip edge.--The data were also analyzed by determining relations of growth to distance from the edge of the undozed strip (table 2). After 11 years diameter growth still decreased with distance from the timber edge, continuing the trends of the 5-year examination. However, only trees on the 2-foot reserve strip showed significantly greater growth than trees on the control plot. Height growth on thinned areas was not significantly different from that on the control area after 11 years, except for dominant and codominant trees on the 2-foot strips; time is canceling out effects of thinning on height growth.

Volume growth.--Annual net growth (cubic feet) of trees on the 2- and 6-foot reserve strips was significantly greater than that of trees on the control areas (table 3). However, when the areas that were dozer bladed are included in the calculation, growth per acre on the 2-foot reserve strips (the only treatment that significantly increased diameter growth) is only about 20 percent of that on the control areas (table 3). Dozered areas were still nonstocked in 1964.

Table 2.--Average diameter and height growth of lodgepole pine 5 and 11 years after thinning, by distance from edge of reserve strip

Strip	Diameter growth				Height growth			
	Dominants and codominants		Intermediates and suppressed		Dominants and codominants		Intermediates and suppressed	
	5 yr.	11 yr.	5 yr.	11 yr.	5 yr.	11 yr.	5 yr.	11 yr.
Reserve:	Inches				Feet			
0-2 ft.	0.41*	0.91*	0.16*	0.32*	2.4*	6.4*	1.1	2.8
2-4 ft.	0.37	0.72	0.10	0.20	3.5	7.5	1.3	3.3
4-6 ft.	0.22	0.58	0.11	0.18	3.8	6.8	1.4	3.3
Control	0.28	0.60	0.05	0.08	4.2	8.0	1.0	2.4

* Means significantly different from control (5-percent level of probability).

Table 3.--Annual volume growth per acre by reserve strip width

Strip	Volume growth	
	Reserve strip area[1]	Total area[2]
Reserve:	Cubic feet per acre	
2 ft.	207 ± 38	30
6 ft.	262 ± 48	87
12 ft.	161 ± 27	80
Control	144 ± 17	144

[1] Plus or minus values are one standard error of the means and represent limits within which the means fall at the 67-percent level of confidence.

[2] Reserve strips plus dozered strips.

DISCUSSION AND CONCLUSIONS

The greater diameter growth of combined intermediate and suppressed trees compared to that of combined dominant and codominant trees indicates the greater initial suppression of the intermediate and suppressed trees and the greater differential between their actual and potential growth. Strong response of these trees is fairly common when thinning has released all crown classes.

The responses obtained in this study are similar to responses for diameter increment reported in other studies on thinning lodgepole pine. A brief comparison follows:

Authority	Response	Location
Roeser, 1949[4]	$1\frac{1}{2}$ to 3X	Colorado
Mowat, 1949[5]	$1\frac{1}{2}$ to $2\frac{1}{2}$X	Oregon, Washington
Alexander, 1956[6]	$1\frac{1}{2}$ to 2X	Colorado
Barrett, 1961[7]	$1\frac{1}{2}$ to 2X	Oregon
Present study	2X	Montana

The height growth data show that although trees were no doubt disturbed by thinning, they apparently are recovering, and real differences due to thinning have all but disappeared.

Generally speaking, the objectives in thinning are to sustain the growth of trees and to increase the total yield of useful material from the stand. This is accomplished by growing fewer trees to larger diameters than those usually found in unthinned stands. The only treatment that significantly increased both diameter growth and volume growth on the reserve strips was the 2-foot-wide strips. To accomplish this, 86 percent of the area was left unstocked (even after 11 years, dozered strips were unstocked), resulting in an overall volume increment of only 20 percent of the increment on unthinned areas. Considerable growing stock was sacrificed for the benefits gained.

It is possible that bulldozer thinning may be useful to lessen the overall thinning job when used in combination with conventional methods of thinning, such as hand thinning of reserve strips. However, it is not recommended as a tool for thinning young, overdense stands of lodgepole pine without additional effort to achieve desirable spacings.

---

[4] Roeser, J., Jr. Results of thinning lodgepole pine. Timberman 50(6): 112, 114. 1949.

[5] Mowat, E. L. Preliminary guides for the management of lodgepole pine in Washington and Oregon. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta. Res. Note 54, 10 pp. 1949.

[6] Alexander, R. R. Two methods of thinning young lodgepole pine in the central Rocky Mountains. J. Forest. 54: 99-102. 1956.

[7] Barrett, J. W. Response of 55-year-old lodgepole pine to thinning. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta. Res. Note 206, 8 pp. 1961.

AFPS Ogden Utah

FOREST SERVICE CREED

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's Forest Resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

Research Note

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

U.S. Forest Service
Research Note INT-70 1967

EFFECT OF THINNING ON THE SPECIFIC GRAVITY OF WESTERN LARCH CROP TREES

David P. Lowery and Wyman C. Schmidt[1]

ABSTRACT

Thinning programs have been started that will eventually encompass a million acres of the larch-type timber stands. The objective is to speed up growth in a selected number of trees. This study was made to determine how reduction in stand competition affects specific gravities of such trees. Increment cores taken from trees in study plots that were thinned 15 years earlier indicate that specific gravities did increase and that these increases could be related to the reduction in stand competition.

Although western larch (Larix occidentalis Nutt.) has limited range in the United States, it is one of the more valuable timber species in the northern Rockies. The relatively high specific gravity and corresponding strength characteristics make larch lumber and plywood especially well suited for structural purposes.

Many natural stands of young larch, growing on burned and harvested areas, are badly overstocked. Thinning programs that will eventually encompass a million acres in the larch type have been started. Objectives of these programs are to concentrate the growth on fewer trees and to produce larger trees at an earlier age. The usual response of a tree to reduced competition or thinning is increased growth. However, this response may be delayed for a few years until the tree's crown and root system have expanded and can utilize the added growing space.

[1] Forest Products Technologist and Associate Silviculturist, respectively, stationed in Missoula, Montana, at the Forestry Sciences Laboratory, which is maintained in cooperation with the University of Montana.

Specific gravity often increases after thinning because of the increase in available soil moisture which favors extended summerwood growth. When stand competition has been renewed, specific gravity may decrease as a result of the intensified use of the available soil moisture.

It is generally recognized that stand competition has a major influence on the growth rate of individual trees. Paul (2)[2] and others conclude, as a result of research on other tree species, that specific gravity is closely correlated with growth rate--if the increased growth results in an increase in the summerwood. In general, specific gravity of summerwood averages two or three times that of springwood. Smith (4), working with Douglas-fir, established a very close relation between percent summerwood and specific gravity. Apparently, specific gravity fluctuates in response to the environmental factors that favor development of either springwood or summerwood.

Spurr and Hsiung (5) cite several studies that indicate that specific gravity generally increases from pith to circumference. Other studies indicate that specific gravity is sometimes correlated with age, ring width, exposure, and nature of terrain, but is not necessarily correlated with site class, stand density, stem diameter, or crown class. Roe and Schmidt (3) showed that diameter, basal area, and cubic-foot volume growth on individual trees increase when larch stands are thinned. No information is available on how reduced stand competition affects the specific gravity of western larch crop trees. The question remains: What effect will thinning have on the specific gravity of larch? This study was made to answer this question.

STUDY AREA AND PROCEDURE

Five 1/2-acre-square plots were established in 1949 on the Lolo National Forest in Montana at an elevation of 4,200 feet. Slopes range from 25 to 55 percent and exposures are principally north to northeast.

The study plots were established in a stand consisting principally of western larch trees, and lesser numbers of lodgepole pine and Douglas-fir. Ponderosa pine, Engelmann spruce, grand fir, and subalpine fir were also found. The stand was about 50 years old and originated following a burn. The average site index for the stand was determined as 52 feet at 50 years (site class III) according to Cummings' classification curves (1).

Four of the five plots were randomly selected for thinning treatments. The fifth plot was left unthinned to serve as a control. Crop trees were chosen and identified on all plots at the rate of about 150 trees per acre, spaced roughly 15 feet apart. Preference was given to western larch, ponderosa pine, Douglas-fir, and lodgepole pine in that order. Only dominant and codominant trees of good form and of fair to good vigor were selected as crop trees.

---

[2] Underlined numerals in parentheses refer to numbered items in Literature Cited, at end of this paper.

On plots 1 and 2, the "D+4" rule of thumb was applied to individual crop trees. All trees were cut from around each crop tree for a radial distance in feet equal to the diameter of the tree in inches plus 4.

On plots 3 and 4, trees were cut for a radius of 3 to 6 feet from the crown edge on at least three sides of each crop tree.

Trees were removed in October 1949 by cutting the smaller stems and girdling and poisoning the larger stems. All larch and ponderosa pine crop trees were pruned to a height of about 18 feet. Pruning of live branches sometimes decreases growth and specific gravity, but the effect was probably negligible in this study because very few live branches were removed.

Table 1.--Mean diameter, number of trees, and basal area on study plots before thinning

Treatment and plot number	Mean d.b.h.	Trees per acre	Basal area per acre
	Inches		Square feet
1	3.4	1,586	103.0
2	3.8	1,396	111.0
3	3.9	1,410	118.0
4	3.2	1,886	106.0
5	3.9	1,668	135.0

Measurements at 5-year intervals included diameter and heights of individual crop trees and plot basal areas. Increment cores from all larch crop trees 15 years after thinning were extracted with a calibrated increment borer and were used for determining specific gravity. All field measurements were made in the fall after the year's growth had been completed.

In the laboratory, the cores were immersed under water for at least 24 hours to bring them to a green condition. Then, each core was cut at a point 15 growth rings in from the cambium. The specific gravity of the two segments, before and after treatment, based on green volume and ovendry weight was then determined by the method described by Wahlgren and Fassnacht (6). These data were subjected to covariance analysis.

RESULTS AND DISCUSSION

The average specific gravity of crop trees on all plots, thinned and unthinned, increased during the 15-year study period (table 2). However, the greatest changes were in the thinned plots. Increases in the thinned plots ranged from 0.032 (plot 4) to 0.049 (plot 1).

Table 2.--Basal areas for all trees, and basal areas, mean diameters, and changes in average specific gravity of the larch crop trees

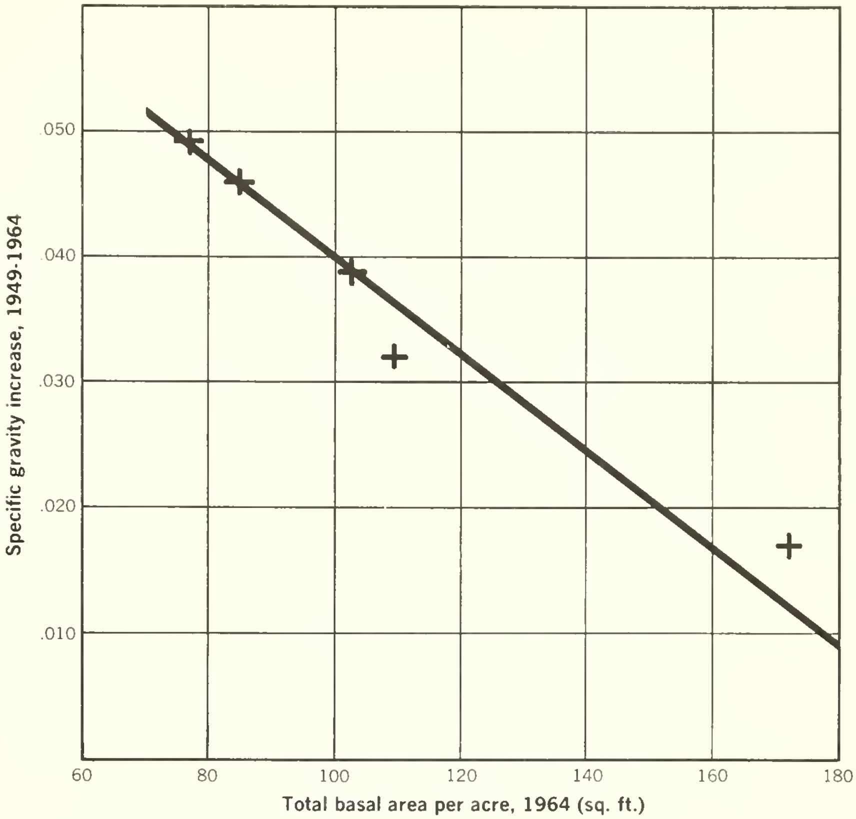
Treatment and plot number	Basal area all trees 1949	Basal area all trees 1964	Larch crop trees: Number	Basal area 1949	Basal area 1964	Mean d.b.h. 1949	Mean d.b.h. 1964	Average specific gravity: Before 1949	After 1949	Increase
	Square feet per acre		Per acre	Square feet per acre		Inches	Inches			
D+4 (1)	44.2	75.6	138	26.6	42.8	6.0	7.6	0.514	0.563	0.049
D+4 (2)	58.8	83.8	141	23.6	36.6	5.5	6.9	.510	.556	.046
Crown (3)	81.6	102.0	114	21.0	32.0	5.8	7.2	.497	.536	.039
Crown (4)	73.4	109.2	154	30.8	49.8	6.1	7.7	.503	.535	.032
Unthinned (5)	135.0	172.0	124	29.2	39.6	6.6	7.7	.501	.518	.017

Meanwhile the increase in the unthinned plot was only 0.017. The average increase in specific gravity for the unthinned plot can probably be attributed to the change in specific gravity that occurs with larger diameter. Percent summerwood was not determined, but examination of cores showed more summerwood present in cores from trees on the thinned plots than in cores from trees on the unthinned plots.

In order to evaluate the difference in specific gravity change (1949-1964) between the thinning and control treatments, variances between and within the replicated plots were assumed to be applicable to the control, represented by a single plot. Initial tree diameter (1949) was used as a covariate to adjust for starting tree-size differences between plots of the treatments. In this analysis, the difference between thinned and unthinned plots was established at the 0.001 level. The results of this analysis therefore verified the apparent differences between plots exhibited by the raw data.

The increase in specific gravity during the 1949-1964 period was strongly related to the total basal area in 1964 (fig. 1). This linear relation demonstrates that specific gravity increased most on plots having the least basal area stocking. After 15 years, total basal area growth on the unthinned plot still exceeds that on the thinned plots because it more fully occupies the site. However, without further thinning, total basal areas on all plots will eventually reach about the same level, and differences in specific gravity will probably disappear. In the meantime, diameter and basal area growth on the thinned areas is being channeled to fewer and better trees. Such trees, as a result, will grow to larger sizes sooner. Besides being larger than their unthinned counterparts, these trees will have a bonus of superior density and strength properties.

Figure 1.--Effect of total basal area on average 15-year change in specific gravity of western larch crop trees.



CONCLUSIONS

The results of this study show that wood quality, as indicated by specific gravity, is improved by reducing stand competition. Specific gravity increases more on larch crop trees in thinned stands than comparable trees in unthinned stands. The rate of increase in specific gravity is related to the intensity of competition as determined by basal area--the greater the competitive intensity, the less the increase in specific gravity.

The trends shown in this study should interest forest managers who manage stands destined for structural lumber or for yield of actual wood. Not only does reduction of competition increase the diameter and basal area growth of larch crop trees, it also increases the specific gravity and consequently improves the properties of this important species.

LITERATURE CITED

1. Cummings, L. J.
   1937. Larch-Douglas-fir board-foot yield tables. U.S. Forest Serv., Northern Rocky Mountain Forest and Range Exp. Sta., Applied Forestry Note 78, 3 pp., illus.

2. Paul, B. H.
   1963. The application of silviculture in controlling the specific gravity of wood. U.S. Dep. Agr. Tech. Bull. 1288, 97 pp., illus.

3. Roe, A. L., and W. C. Schmidt.
   1965. Thinning western larch. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Paper INT-16, 10 pp., illus.

4. Smith, D.
   1956. Effect of growth zone on specific gravity and percentage of summerwood in wide-ringed Douglas-fir. U.S. Forest Serv., Forest Prod. Lab. Rep. 2057, 9 pp., illus.

5. Spurr, S. H., and W. Hsiung.
   1954. Growth rate and specific gravity in conifers. J. Forest. 52: 191-200, illus.

6. Wahlgren, H. E., and D. L. Fassnacht.
   1959. Estimating tree specific gravity from a single increment core. U.S. Forest Serv., Forest Prod. Lab. Rep. 2146, 24 pp., illus.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

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

U.S. Forest Service
Research Note INT-71 1967

A SYSTEM FOR AUTOMATICALLY RECORDING WEIGHT CHANGES IN SAPLING TREES

by

Harold F. Haupt and Bud L. Jeffers[1]

ABSTRACT

Describes an accurate and simple system for taking continuous weight records of sapling-size trees. Measurements obtained using this system have helped in describing the mechanism of interception storage in tree crowns during snowfall.

Knowledge of the hydrologic process of snow interception is limited, particularly in respect to quantities of snow caught by coniferous tree crowns. In past studies, snow interception has been calculated as the difference between the water equivalent of the snowpack in a forest opening and that of the snowpack beneath the tree canopy some distance away. This difference, even on a theoretical basis, is of questionable value because it assumes that the same quantity of snow falls in the opening as upon the forest canopy.

In 1965, we developed a direct system for measuring snow interception by conifer crowns. After 2 years of testing--carried out in cooperation with the Department of Forestry and Range Management at Washington State University--the success of the system has been proven, both in terms of simplicity of operation and accuracy of data.

We already have published one report from data collected using this system.[2] It describes the mechanism of interception storage during a snowfall. This paper deals only with the design and mechanics of duplicating this system in which cut sapling-size trees are suspended from a cable in such fashion that a continuous weight record can be taken for each tree.

---

[1]Principal Forest Hydrologist and Forestry Research Technician, respectively, on the staff of Intermountain Forest and Range Experiment Station, Ogden, Utah. Both are stationed in Moscow, Idaho, at the Forestry Sciences Laboratory, which is maintained by the Forest Service in cooperation with the University of Idaho.

[2]Satterlund, Donald R., and Harold F. Haupt. Snow catch by conifer crowns. Water Resources Res. 3(4): 1035-1039, illus. 1967.

METHOD OF SUSPENSION

We have three 25-foot cedar poles set upright in a triangular layout within a small clearing on our test site at Priest River Experimental Forest in northern Idaho. Strung between these poles is ½-inch cable, from which six small boat pulleys are hung (two along each run of cable). This permits six trees to be weighed at a time.

A single-tree setup is shown in figure 1. The cable used to suspend the tree from the pulley is of steel 1/8 inch in diameter. On one end of this cable is bolted a C-hook, which is attached to a wire loop affixed to the top of the tree. The other end of the cable is connected by a ball-bearing swivel to a short length of standard steel (float) tape, which is perforated. The perforations engage the drive sprocket on the recorder. The other end of the steel tape is fastened to a spring-tension scales (see figure 2), which is hooked onto one of the cedar poles. The swivel prevents the steel tape from twisting free of the drive sprocket during windy periods.

AUTOMATIC RECORDING APPARATUS

Although almost any model of water-level recorder, drum, or roll chart should operate satisfactorily, we used a surplus Friez FW-2 recorder[3] with a 192-hour drive. In order to convert it into a weight recorder, we replaced the float wheel with a small, custom-built drive sprocket.

This drive sprocket, which was machined from 17/32-inch O.D. brass rod, has 10 inserted "teeth" made of 16-gage brads. The center of the rod is drilled to fit onto the float wheel shaft. Once on the shaft the original float wheel clamp prevents the sprocket from slipping (figure 2).

The modified recorder is actuated by placing it next to the steel tape until the sprocket teeth engage the perforations. As the spring in the scales is stretched or contracted with changes in weight, a record of movement is made by the recorder. The recorder need not be bolted to the shelter base.

The smallest vertical unit on the FW-2 chart corresponds approximately to a 2-1/4-pound change on a 300-pound spring-tension scales.[4] Because the arm assembly traverses, the apparatus will record any amount of snow that does not exceed the capacity of the scales used.

RESULTS

The sensitivity of the system is excellent. We can detect deposition of snow, rain, dew, frost, or loss of tissue moisture from the severed tree in small quantities. Weight changes can be measured to at least one-half pound. This represents only 0.00122 inch (water equivalent) of catch over a projected crown diameter of 10 feet.

Pen traces or interceptographs on the FW-2 chart resemble those illustrated in figure 3. The interceptographs shown characterize one type of sequence in which snow builds up on needle clusters and limbs only to unload rapidly from tree to ground with a change from falling snow to rain.

---

[3] Use of trade names herein is solely for identification and does not imply endorsement by the U.S. Forest Service.

[4] Hanson "The Viking," Model 8930, or equivalent.

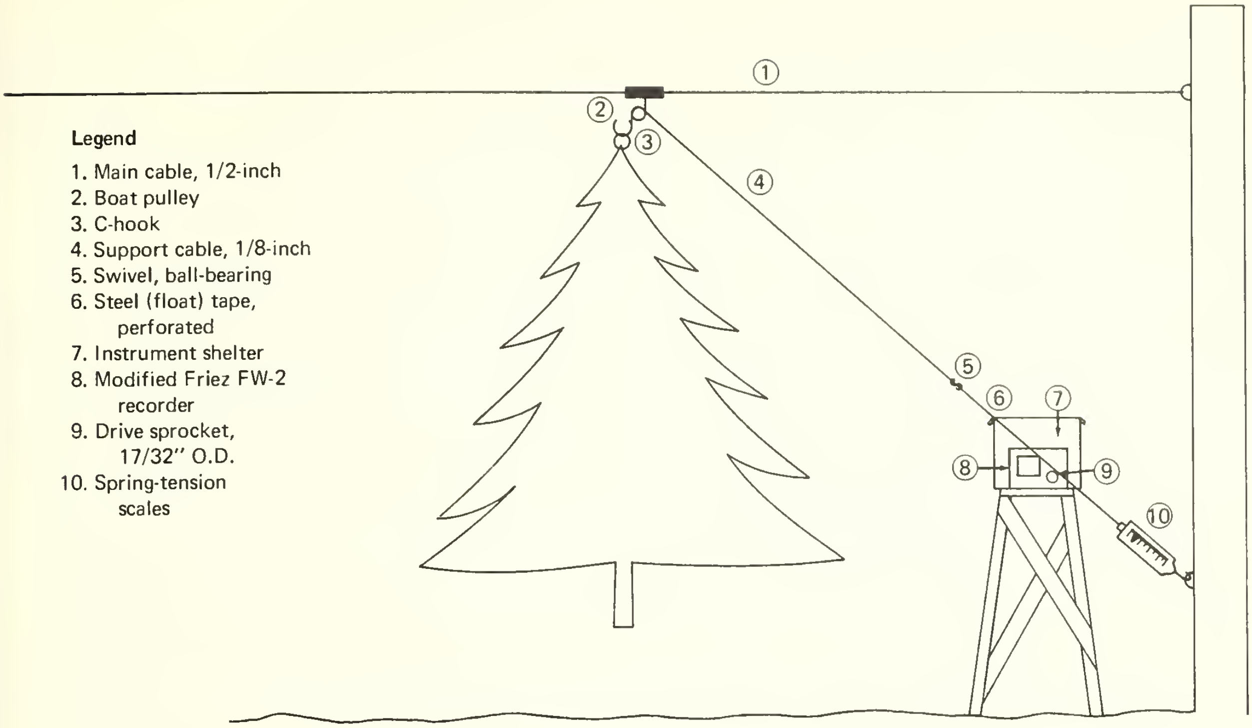


Figure 1.--A schematic view of the suspension system-automatic recording device for weighing sapling trees.

Figure 2.--Closeup of the recording apparatus and spring-tension scales.

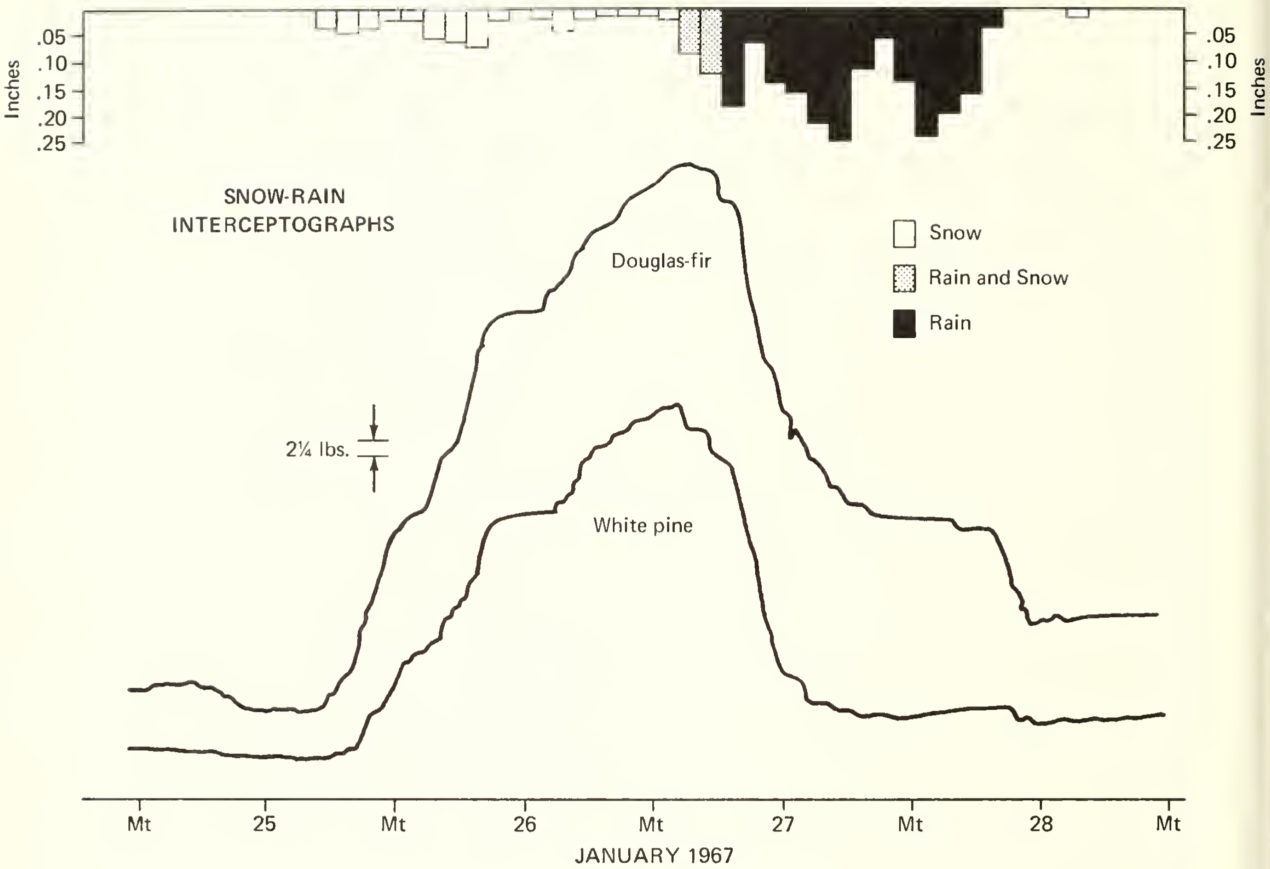


Figure 3.--Pen traces or interceptographs for two coniferous species.

Research Note

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

U.S. Forest Service
Research Note INT-72

1967

INHIBITORS OF GERMINATION AND GROWTH FROM RED ELDERBERRY: A LABORATORY EVALUATION

by

W. T. McDonough and R. K. Tew[1]

ABSTRACT

Field observations on subalpine rangeland had indicated that emergence and growth of planted grasses was reduced in the vicinity of red elderberry (Sambucus racemosa var. microbotrys). To determine whether antibiotic substances were involved in this effect, aqueous extracts of various parts of elderberry were tested for inhibition of germination and seedling growth of grasses and other associated species. Inhibition of germination was weak, and was diminished further or eliminated by such treatments of the extract as moderate dilution or adsorption of the active component(s) on charcoal. In pot culture in the greenhouse, seedling growth of grasses was not reduced by a surface mulch of elderberry leaves. It was concluded that the observed depression of emergence and growth that was observed in the field could not be attributed to the liberation of toxic substances from elderberry, unless special conditions exist in the field which are not duplicated in the laboratory or greenhouse.

EFFECTS AND IMPORTANCE OF INHIBITORS

One plant may inhibit the growth of other plants in its vicinity by liberating inhibitory substances into the environment (Borner 1960). This property may help determine the importance of individual species in a community: the inhibitor-producing plants will

---

[1] Associate Plant Physiologists, stationed in Logan, Utah, at the Forestry Sciences Laboratory, which is maintained in cooperation with Utah State University.

face reduced competition, and they will grow and spread at the expense of other species sensitive to the inhibitory substances.

Inhibitory effects of aqueous leachates from crop plants have been studied extensively, but only recently has research been directed toward the possible role of inhibitors in determining species composition and importance in the vegetation of rangelands. Muller et al. (1964) studied the effect of volatile growth inhibitors in aromatic shrubs in California. Reid et al. (1963) and Wilkie and Reid (1964) demonstrated the inhibitory effect of foliar leachates from four species of sagebrush on germination and growth of several crop species and native grasses. Jameson (1966) found that juniper litter inhibited the growth of blue grama.

A study of the possible production of growth inhibiting substances in red elderberry (Sambucus racemosa var. microbotrys (Hitchcock et al. 1959)) was prompted by field observations which suggested that germination of several species of introduced grasses had been delayed or prevented in plots where elderberry had been growing. In these plots, few grass seedlings emerged within areas from which elderberry had been removed. It therefore seemed desirable to determine the effectiveness of aqueous extracts of various parts of elderberry for inhibitory influence on germination and early seedling growth of several native and introduced species.

Red elderberry (figure 1), also called bunchberry elder, is one of the most common of the western elderberries in the central Rocky Mountains and the general Intermountain region. It extends from southwestern Montana eastward to South Dakota, southward to New Mexico, and westward to Arizona and Nevada, chiefly on moist sites in the upper ponderosa pine, aspen, spruce, and subalpine belts (U.S. Dep. Agr. 1937).

METHODS AND MATERIALS

Collections of aerial shoots and rhizomes of red elderberry were made at approximately 8,000 feet near Strawberry Reservoir on the Uinta National Forest, and in Logan Canyon on the Cache National Forest, Utah. Fresh plant material was processed the day of collection. Otherwise, the plant parts were dried in a current of air at room temperatures of 22-25°[2] for 72 hours.

Preliminary Experiments

In preliminary experiments, several methods of extraction were tested. Air-dry elderberry leaves were homogenized in distilled water for 1 minute, and the homogenate was filtered and refrigerated until used in experiments on the same day. In other preliminary experiments, fresh leaves and ground portions of air-dry stems and rhizomes were extracted. Blending time and length of time that the extract was in contact with the leaf tissue were also tested as factors affecting the inhibitory activity of the extract. All methods of extraction produced essentially the same results.

[2] All temperatures shown are °C.

Figure 1.--A partially excavated clone of red elderberry from the Uinta National Forest. Aerial stems are in the deciduous condition.

Extracts made from air-dry leaves were as potent as those from fresh leaves and surpassed those from air-dry stems and rhizomes. The extract used for the results reported in this paper was prepared from air-dry leaves that were homogenized for 1 minute before filtration.

Seeds of grasses used in studies of germination and seedling growth were obtained from a commercial source, and included species commonly used in the revegetation of subalpine rangeland. The species used in preliminary experiments were intermediate wheatgrass (Agropyron intermedium), tall oatgrass (Arrhenatherum elatius), smooth brome (Bromus inermis), orchard grass (Dactylis glomerata), and timothy (Phleum pratense). Seeds of native forbs were collected from aspen or grass-forb communities on the Uinta National Forest during the summer of 1965. These species were chosen because they grow in the same areas as red elderberry. All seeds were stored in vapor-tight bottles at 2° until used, except for the seeds of Polemonium foliosissimum, which were stored under room conditions.

In preliminary experiments, the effect of a leaf extract (10 g./100 ml.) on the germination of the five species of grass was determined according to the method of Lawrence and Kilcher (1962). Germination of all species was inhibited to a highly significant extent (0.1-percent probability level). However, since there was doubt that such a concentration could be attained in the field, and since there may be osmotic effects at this concentration (Anderson and Luocks 1966), the air-dry weight of leaves used in preparation of extracts was reduced by two-thirds (to 3.3 g./100 ml.) for the experiments reported below.

Later Tests

Additional germinative tests were run on six grasses and four forbs (tables 1 and 2). Seeds (approximately 50 per dish) were placed in 9-cm. petri dishes on double layers of Whatman No. 1 filter paper[3] wetted with 4 ml. of distilled water or extract. The dishes with seeds were placed under 8-hour photoperiods at 22° and 16-hour dark periods at 17°. Temperatures were controlled to within 1°. Seeds were inspected daily for germination (growth of the embryonic root through the covering layers), and final germination percentages were determined when no additional germination had occurred for 3 days. Dishes and seeds under each treatment were replicated, so that results given in the text and tables of this paper represent the means of four determinations plus or minus standard deviations. The data on percentages of seed germination were analyzed statistically, with and without arcsine transformations. Indications of significance were the same by either method.

Experiments testing seedling growth of three grasses were done under greenhouse conditions in 6-inch clay pots filled with a sandy loam. For each species, four pots each were used for treatment and control. Following the planting of seeds at a depth of one-half inch (12 per pot, thinned to 4), 10 grams air-dry weight of elderberry leaves were crushed and distributed uniformly over the surface of each treated pot. The soil surface of control pots was left bare, since any other kind of mulch might have had unknown promotive or inhibitory effects. The soil surface was watered on alternate days with 250 ml. of tapwater.

RESULTS

Seed Germination

In tests of germination of six species of grass (table 1), germination rates and germination percentages were reduced for all species, except pubescent wheatgrass (rate) and smooth brome (final percentage). In further tests with germination of foxtail (the most sensitive species), pretreatment of the extract by storage for 6 days at 2° or by boiling for 1 minute had no effect on the inhibition of germination. Inhibition was eliminated when the extract was clarified by filtering it through activated charcoal; final percentages of germination were 96% ± 1 for treated samples, and 94% ± 1 for controls. Similarly, a 1:1 dilution of the untreated extract completely eliminated the inhibition (95% ± 2).

The extract and dilutions generally inhibited germination in native forbs (table 2). A comparison of mean percentages of germination of seeds imbibed in distilled water or various dilutions of the extract showed that, except for the zero and 1:1 dilutions for *Aquilegia*, all differed significantly from all other treatments for each species at the 5-percent level.

---

[3] Use of trade names herein is solely for identification and does not imply endorsement by the U.S. Forest Service.

Table 1.--Final percentages of germination of grass seeds imbibed on filter paper in distilled water (control) and in extract of elderberry leaves

Species	Percent germination	
	Water	Extract
Intermediate wheatgrass Amur (*Agropyron intermedium*)	[1] 100 (2)	87 ± 2 (3)**
Meadow foxtail (*Alopecurus pratensis*)	97 ± 1 (5)	64 ± 4 (7)**
Pubescent wheatgrass Topar (*Agropyron trichophorum*)	96 ± 1 (4)	84 ± 3 (4)**
Slender wheatgrass (*Agropyron trachycaulum*)	100 (3)	96 ± 1 (5)**
Smooth brome Manchar (*Bromus inermis*)	84 ± 2 (3)	87 ± 2 (4)
Tall oatgrass Tualatin (*Arrhenatherum elatius*)	76 ± 4 (3)	69 ± 3 (4)*

[1] Numbers in parentheses indicate days to one-half of the final germination percentage.

*Difference between control and seeds treated with extracts is significant at 5-percent level of probability.

**Difference significant at 1-percent level of probability.

Table 2.--Germination percentages of seeds of native forbs imbibed in water or extract of elderberry leaves

Species	Extract	Germination
Colorado columbine (*Aquilegia coerulea*)	H_2O	60 ± 4
	1:4	54 ± 4
	1:1	28 ± 2
	0	31 ± 2
Fendler meadowrye (*Thalictrum fendleri*)	H_2O	74 ± 2
	1:1	83 ± 1
	0	61 ± 3
Leafy polemonium (*Polemonium foliosissimum*)	H_2O	27 ± 3
	1:1	22 ± 2
	0	8 ± 1
Nettleleaf horsemint (*Agastache urticifolia*)	H_2O	56 ± 2
	1:4	48 ± 4
	1:1	34 ± 3
	0	21 ± 1

Seedling Growth

The mulch of elderberry leaves had no detrimental effect on growth of seedlings of foxtail, intermediate wheatgrass, and slender wheatgrass during 1 month; the fresh and dry weights of treated plants equaled or exceeded those of the controls. Any inhibitory effect of the mulch was probably balanced or outweighed by its beneficial effects under greenhouse conditions.

DISCUSSION

To be effective in nature, an inhibitory substance must be strong enough to produce an effect despite a large dilution in the environment, and despite other losses due to adsorption, microbial action, and chemical reaction with other substances. Preliminary field observations suggested that red elderberry somehow inhibited the emergence of introduced grasses, at least during the first year after its removal. However, the inhibitory effect produced in laboratory tests lacked potency; it was diminished by moderate dilution; it was eliminated by filtration through charcoal; and it was not effective in pot culture under greenhouse conditions. Thus, its effectiveness under field conditions appears doubtful unless special conditions exist in the field that were not duplicated in the laboratory.

Elderberry is a rhizomatous shrub (figure 1), and a particular plant may occupy the same site for many years. One rhizome examined had at least 58 annual rings and probably was much older. Therefore, it is possible that inhibitory substances leached from the leaves and rhizomes might be concentrated in the soil in the immediate vicinity of the group of aerial stems. Perennial species are seldom found within the area occupied by well-defined clumps of aerial stems of red elderberry. However, factors of competition other than production of inhibitory substances may be acting to exclude other species.

Laboratory and greenhouse tests did not indicate that inhibitory substances in elderberry are sufficiently potent to be effective under field conditions. To properly determine the existence and ecological significance of any inhibitor, extensive field studies would be needed to establish the presence of the inhibitor in the soil directly beneath and at various distances from clones of elderberry. Association analysis would also be required to determine the spatial relations between red elderberry and associated species.

LITERATURE CITED

Anderson, R. C., and O. L. Luocks.
1966. Osmotic pressure influence in germination tests for antibiosis. Sciences 152: 771-773.

Borner, H.
1960. Liberation of organic substances from higher plants and their role in the soil sickness problem. Bot. Rev. 26: 393-424.

Hitchcock, C. L., A. Cronquist, M. Ownbey, and J. W. Thompson.
1959. Vascular plants of the Pacific Northwest. Part 4: Ericaceae through Campanulaceae. Seattle: Univ. of Wash. Press.

Jameson, D. A.
1966. Pinyon-juniper litter reduces growth of blue grama. J. Range Manage. 19: 214-217.

Lawrence, T., and M. R. Kilcher.
1962. The effect of fourteen root extracts upon germination and seedling length of fifteen plant species. Can. J. Plant Sci. 42: 308-313.

Muller, C. H., W. H. Muller, and B. L. Haines.
1964. Volatile growth inhibitors produced by aromatic shrubs. Science 143: 471-473.

Reid, A., S. W. VerStraten, and C. F. Wilkie.
1963. Antibiotic effects produced by four species of sagebrush in Wyoming. Wyo. Range Manage., Issue 176.

U.S. Dep. of Agriculture, Forest Service.
1937. Range plant handbook. Wash., D.C. U.S. Government Printing Office.

Wilkie, C. F., and A. Reid
1964. Further studies on growth inhibitors in sagebrush. Wyo. Range Manage., Issue 194.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

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

U.S. Forest Service
Research Note INT-73

1967

SOIL MOISTURE DEPLETION BY ASPEN IN CENTRAL UTAH

by

Ronald K. Tew[1]

ABSTRACT

Aspect and elevation of site and age of vegetation affect the amount of soil moisture depleted by aspen (Populus tremuloides Michx.) during the growing season in central Utah. Clones on west aspects used more soil moisture than those on either north- or south-facing slopes. Differences in elevation had little effect on the amount of soil moisture depleted by mature aspen, but sprout stands used significantly greater amounts of soil moisture on the lower elevation sites. As much as 5 inches of moisture was conserved in the upper 6 feet of soil during the first season after aspen removal, but as sprout stands became reestablished, there was a decrease in these moisture savings.

Quaking aspen (Populus tremuloides Michx.) occupies more than 1.3 million acres in Utah. Management of this species, along with its associated understory, is important from the point of view of water yield, grazing, timber, wildlife, and aesthetic values. Aspen roots extend to depths exceeding 9 feet,[2] thereby enabling the tree to deplete soil moisture to those depths. Management of aspen, therefore, should include consideration of its water consumption. Some aspen stands having little commercial value might be converted to shallow-rooted vegetation that has greater economic potential, with a resulting increase in the yield of water from the area. However, many things must be considered before any such conversion practices are attempted. Aspen provides valuable watershed protection. It grows on deep fertile soils and contributes to their development. It is an important browse species for big game and livestock, and its understory produces large amounts of herbage. It has aesthetic value, largely because of its brilliant autumn colors.

---

[1] Associate Plant Physiologist, stationed in Logan, Utah, at the Forestry Sciences Laboratory which is maintained in cooperation with Utah State University.

[2] Gifford, Gerald F. Aspen root studies on three sites in northern Utah. Amer. Midland Natur. 75(1): 132-141. 1966.

For the research program in water yield improvement in the Intermountain area, information on soil moisture depletion by aspen was needed for purposes of comparison. The research reported in the present study was initiated to supply this information with respect to effects of aspect and elevation of site and age of vegetation.

METHODS

Mature aspen clones were selected at six sites in Ephraim Canyon in central Utah. These sites included three aspects (north, south, and west) at each of two elevations (7,900 and 9,200 feet). Few aspen grow below 7,900 feet in this area, although a considerable number occur above 9,200 feet, especially on south-facing slopes. Clones were selected for uniformity in appearance. At each elevation, all study areas were chosen within a quarter mile of each other to provide similar climatic conditions on comparable sites.

At each site, an area 40 by 40 feet was divided into four square plots. Boundaries between plots were trenched to a 2-foot depth, so that the lateral root systems were severed and prevented from transporting water across plot boundaries. To impede regrowth of these roots, roofing paper was placed in the trenches, and the trenches were refilled.

During July 1963, the aspen was clearcut and removed from two of the plots at each site and a young sprout stand was allowed to develop. A buffer strip 20 feet wide also was clearcut on the outer edges of the experimental area at each site. Thus the effects of 12 treatment combinations of aspect, elevation, and cutting on water use by aspen were compared. This arrangement provided for two replications of each combination.

To permit use of a neutron soil moisture probe, access tubing was installed to a 6-foot depth by means of a jackhammer-type drill. Two tubes were randomly located on each of the 24 plots, providing two soil moisture sampling points for each replication of the treatment combinations. Measurements were made on all plots three times (May or early June, late July, and mid-September) each year from 1964 through 1966.

A soil pit 6 feet deep was dug adjacent to each site, the profile was described, and samples were obtained from each horizon. Texture was determined by the Bouyoucos hydrometer method, organic matter content by wet digestion with chromic acid, and lime content by acid neutralization; moisture-holding properties were evaluated with a pressure membrane apparatus.

SOILS

The moisture-holding capacity of the soils on all sites was closely related to the clay content, rock content, and depth of soil development. The soil on all sites had developed from limestone parent material. It was high in clay content, although the amount of clay varied noticeably from one aspect to another. South aspects had soil that was relatively low in clay, approximately 30 percent at both elevations. About 46 inches of rock-free soil had developed on the south-facing slope at the lower elevation. However, in laboratory tests, this soil was found to have only a moderate moisture-holding capacity, as compared with soil from plots on the other aspects at that elevation. At 9,200 feet (the upper elevation) the soil at the south aspect site contained many large rocks. There, only 16 inches of soil had developed, below which lay a considerable amount of sand and rock.

The north aspect at 7,900 feet had the deepest soil, approximately 48 inches. Because clay content was near the 50-percent level throughout the entire profile, moisture-holding capacity was relatively uniform. At 9,200 feet, 33 inches of soil had developed; it was approximately 45 percent clay and its organic matter content was high. The solum had very high moisture-holding properties, but an abrupt decrease occurred at the boundary of the somewhat rocky parent material.

Soil on the west aspect at 9,200 feet was 48 inches deep; a 12-inch B_2 horizon contained 60 percent clay. Little sand or rock was present. Moisture-holding capacity was high. At 7,900 feet the soil on the west aspect was not as deep, consisting of only 29 inches of well-developed soil, but the moisture-holding capacity was high throughout the entire 6 feet.

SOIL MOISTURE DEPLETION

The effects of differences in aspect and elevation of site, and age and density of vegetation on soil moisture depletion were tested during three growing seasons. An analysis of variance was used to determine whether differences in results were significant. The effect of each variable was confounded with soil differences and clonal variation among sites, so that only broad generalizations are possible.

Aspect.--During all 3 years, the largest amounts of soil moisture were removed by aspen clones growing on west exposures (table 1). Moisture depletion on north- and south-facing sites at both elevations was similar during all years. However, the difference between mature and sprout stands was greatest on north-facing slopes. There, in 1964, at the upper elevation, the sprout stand used 5 inches less soil moisture than the mature stand.

More soil moisture was depleted on all aspects during 1964 than during either 1965 or 1966 because less precipitation was received during the 1964 growing season. In contrast, an exceptionally wet year occurred in 1965, and as a result, only small differences in soil moisture depletion between aspects were observed.

Elevation.--Soil moisture losses under mature aspen on comparable sites were similar at both elevations. However, sprout stands consistently used more moisture at the lower elevation. As a result, the data show that a greater saving of soil moisture was achieved at the higher elevation by clearcutting (table 1). The difference is especially pronounced for the wet season of 1965.

Age of vegetation.--Mature stands of aspen used significantly more moisture than did sprout stands during all 3 years. The cutting treatment, which replaced mature stands with sprouts, had the greatest influence on north aspects at both elevations (table 1). The differences between mature and sprout stands decreased on all aspects from 1964 to 1966, as would be expected when the young sprouts grew and more fully occupied the site. Depending on site characteristics, the clearcutting treatment resulted in conservation of 1 to 5 inches of soil moisture in the upper 6 feet of soil.

Quantity of vegetation.--The number and basal area of aspen stems were inventoried on all plots of mature aspen (table 2). On comparable aspects, the plots at the higher elevation had a greater tree population. More basal area at the higher elevation on south and west aspects also was noted, but there was little difference between elevations on north aspects.

Table 1.--Soil moisture depletion during three growing seasons

Site and year	Mature stands	Sprout stands	Difference
	Inches		
	7,900-FOOT ELEVATION		
North aspect			
1964	7.72	4.31	3.41
1965	4.23	1.30	2.93
1966	5.13	3.98	1.15
South aspect			
1964	7.46	6.43	1.03
1965	4.72	3.41	1.31
1966	6.41	5.78	0.63
West aspect			
1964	9.91	9.06	0.85
1965	5.82	5.45	0.37
1966	7.63	7.09	0.54
	9,200-FOOT ELEVATION		
North aspect			
1964	8.25	3.04	5.21
1965	4.66	0.07	4.59
1966	7.34	2.53	4.81
South aspect			
1964	7.44	5.70	1.74
1965	4.45	0.87	3.58
1966	7.17	6.21	0.96
West aspect			
1964	9.56	7.31	2.25
1965	7.01	1.71	5.30
1966	8.37	6.91	1.46

Table 2.--Average stem density and basal area on plots of mature aspen

Aspect	Stem density per acre		Basal area	
	7,900-ft. elev.	9,200-ft. elev.	7,900-ft. elev.	9,200 ft. elev.
North	152	250	180.8	148.6
South	163	207	139.5	204.5
West	120	272	166.4	252.4

Soil moisture depletion was consistent with vegetation density when differences between mature and sprout stands were considered. Little difference could be noted between the mature stands at the two elevations, so that differences in vegetation density are unimportant. From evidence in the trenches dug on each plot, it appeared that aspen roots were quite uniformly distributed over the entire plot, regardless of the location or spacing of trees.

Season of use.--The greatest depletion of soil moisture occurred during the early part of the growing season. For example, in 1966 the average soil moisture depletion for all plots at 7,900 feet elevation was 4.78 inches between May 25 and July 13. From then until September 22 another 1.23 inches was depleted, making a total of 6.01 inches. During the same time interval, for the sites at 9,200 feet the moisture depletion was 5.56 and 0.87 inches. The time of maximum depletion varied from year to year, depending to some extent on the timing and amount of summer rainfall in relation to the time soil moisture measurements were made. Late season moisture losses generally were from the lower portions of the soil profile.

Depth of loss.--On all plots, use of soil moisture decreased with increasing depth in the profile. Table 3 shows maximum water loss on the various sites, that is, the water loss that might be expected, calculated on the basis of the observed maximum differences between spring and fall readings obtained during the 3 years. Approximately equal amounts were taken from the upper 4 feet of soil by mature and sprout stands. Mature aspen showed only moderate decreases in moisture use in soil levels above the 5-foot depth. A more rapid decrease was observed on plots having sprout stands; the quantities of water removed from the 5- and 6-foot depth levels were relatively small. At both elevations, this pattern of soil moisture removal was especially pronounced on north aspects and was least evident on south aspects.

EVAPOTRANSPIRATION

Table 4 shows the total evapotranspiration during three growing seasons calculated as growing-season precipitation plus soil moisture depletion. This assumption neglects any deep seepage or overland flow that might have occurred during the growing season. Precipitation during individual storms was greater at the higher elevation than at the lower, but the total precipitation for the higher sites was less because the growing season was shorter.

Evapotranspiration during 1964 and 1966 was similar on comparable sites, although slightly greater losses were observed in 1966 from sprout stands. Little difference was noted between elevations. During 1965, when precipitation was exceptionally great, evapotranspiration was also greater, resulting in approximately 3 inches more moisture loss than in either 1964 or 1966. Soil moisture depletion was much less, however, so that more soil moisture was retained at the end of the growing season.

DISCUSSION

Soil moisture depletion by aspen is affected by the aspect and elevation of the site and by the age of the vegetation. Some of the variation attributable to aspect and elevation was probably caused by differences in soil depth and quality. Because south-facing slopes receive more solar energy than either the north- or west-facing slopes, they might be expected to have higher rates of soil moisture loss. Since, instead the highest rates were for west-facing slopes, other factors, such as differences in soil properties, must dominate.

Table 3.--Patterns of soil moisture depletion by aspen according to plot treatment

Treatment	Maximum water loss[1] By 1-ft. depth intervals 0-1	1-2	2-3	3-4	4-5	5-6	Total	Difference mature trees vs. sprouts
	Inches							
7,900-FOOT ELEVATION								
North aspect								
Mature trees	1.75	1.65	1.68	0.90	1.19	0.85	8.02	
Sprouts	1.51	1.33	0.92	0.87	0.23	0.39	5.25	2.77
South aspect								
Mature trees	1.44	1.72	1.13	1.32	1.13	0.75	7.49	
Sprouts	1.67	1.74	1.47	1.17	0.78	0.50	7.33	0.16
West aspect								
Mature trees	2.48	2.85	2.44	1.56	1.62	1.37	12.32	
Sprouts	2.62	2.96	2.64	1.65	1.06	0.62	11.55	0.77
9,200-FOOT ELEVATION								
North aspect								
Mature trees	2.07	1.57	1.62	1.20	1.44	1.51	9.41	
Sprouts	1.74	0.89	0.68	0.50	0.44	0.42	4.67	4.74
South aspect								
Mature trees	2.03	1.74	1.25	1.26	1.00	0.96	8.24	
Sprouts	1.90	1.15	1.38	1.20	0.91	0.70	7.24	1.00
West aspect								
Mature trees	2.54	2.32	1.39	1.75	1.26	1.26	10.52	
Sprouts	2.39	1.74	1.48	1.23	0.57	0.51	7.92	2.60

[1] Based on maximum differences observed between spring and fall readings from 1964 through 1966.

Table 4.--Evapotranspirational losses[1] during three growing seasons according to plot treatment and ages of vegetation

Treatment	1964 Precip.	1964 ET.	1965 Precip.	1965 ET.	1966 Precip.	1966 ET.
	Inches					
7,900-FOOT ELEVATION						
North aspect						
Mature trees	3.98	11.70	10.65	14.88	4.80	9.93
Sprouts		8.29		11.95		8.78
South aspect						
Mature trees	3.98	11.44	10.65	15.37	4.80	11.21
Sprouts		10.41		14.06		10.58
West aspect						
Mature trees	3.98	13.89	10.65	16.47	4.80	12.43
Sprouts		13.04		16.10		11.89
9,200-FOOT ELEVATION						
North aspect						
Mature trees	3.78	12.03	9.28	13.94	5.55	12.89
Sprouts		6.82		9.35		8.08
South aspect						
Mature trees	3.78	11.22	9.28	13.73	5.55	12.72
Sprouts		9.48		10.15		11.76
West aspect						
Mature trees	3.78	13.34	9.28	16.31	5.55	13.92
Sprouts		11.09		10.99		12.46
Average						
Mature trees		12.27		15.11		12.18
Sprouts		9.86		12.10		10.59

[1] Based on soil moisture depletion plus precipitation during the growing season.

At both elevations, the greatest differences between mature and sprout stands were observed on north slopes. Therefore, in planning treatment of an area to increase streamflow, aspect should be considered, since north slopes apparently have the greatest potential for supplying additional water.

The difference in treatment effects at different elevations may be related to leafing dates. Lower elevation clones began leafing out approximately May 25 and higher elevation clones began during the first week of June. Since leaves remained on the trees later into the fall at the lower elevation, there was a longer period for transpiration at that level. Perhaps due to this longer period, total use of soil moisture by sprout stands was greater at the lower elevations. However, mature aspen stands on comparable sites used similar amounts of soil moisture at both elevations. If aspen is to be removed for the purpose of increasing water yields, treatments at higher elevations are likely to be most successful.

If savings in soil moisture over a period of several years are desired, some type of control program is required to suppress sprout numbers or growth. If aspen is eradicated and shallow-rooted plants are established, losses that still occur deep in the profile under sprout stands may be eliminated. Whether the deep parent root systems are supporting aspen sprouts or old trees, soil moisture depletion will continue to at least a 6-foot depth, as indicated in table 3.

More must be learned before any specific treatment to increase water yields can be recommended. This study shows that moisture depletion is only temporarily reduced by cutting aspen stands. Conversion to another vegetation type appears to be necessary if moisture losses are to be reduced over any significant period. Potential replacement species for aspen need to be investigated with respect to their rooting depths, their soil moisture depletion patterns, and their ability to become established on aspen sites. Further, the effects, both adverse and favorable, that the conversion may have on the site require investigation. Therefore, no management decision to remove aspen for the purpose of increasing water yields should be made without careful study of site conditions.

Research Note

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

U.S. Forest Service
Research Note INT-74

1967

SOIL MOISTURE DEPLETION BY GAMBEL OAK IN CENTRAL UTAH

by

Ronald K. Tew[1]

ABSTRACT

Aspect and elevation of site and age of vegetation affect the amount of soil moisture depleted by Gambel oak (Quercus gambelii Nutt.) during the growing season in central Utah. More soil moisture was lost at the higher elevation (7,900 feet) than at the lower (6,600 feet) on all aspects. A south-facing site at the higher elevation lost the most moisture, whereas one at the lower elevation lost the least. Most available soil moisture was depleted to a depth of 6 feet on all sites during seasons of normal rainfall. Removing oak and allowing regrowth of a vigorous sprout stand reduced soil moisture depletion nearly an inch during the year following cutting, but by the end of the third year, sprout stands were using up to an inch more soil moisture than mature stands.

Gambel oak (Quercus gambelii Nutt.) occupies large areas on important watersheds adjacent to major population centers in the West. Information on soil moisture depletion by this species is becoming more important as the need for additional water becomes more pressing. It has been shown that between 11 and 13 inches of soil moisture is removed by Gambel oak and associated vegetation from the top 8 feet of coarse-textured soil on a south-facing slope in northern Utah (Tew 1966).[2] The

[1]Associate Plant Physiologist, stationed at Logan, Utah, at Forestry Sciences Laboratory, which is maintained in cooperation with Utah State University.

[2]Tew, Ronald K. Soil moisture depletion by Gambel oak in northern Utah. U.S. Forest Serv. Res. Note INT-54, 7 pp. 1966.

research reported here provides additional information on moisture use by oak growing on finer textured soils having greater water-holding capacities than those previously studied. It also evaluates the influences of aspect and elevation of site and age of vegetation.

METHODS

Mature oak clones were selected at six locations in Ephraim Canyon in central Utah. These sites included three aspects (north, south, and west) at each of two elevations (6,600 and 7,900 feet) that represent the approximate lower and upper boundaries of oak in this area. The clones were selected for uniformity in density, age, and slope at each elevation. Since oak grows taller at the higher elevation, selection of vegetation of uniform size was impossible. At each elevation all clones were chosen within a quarter mile of each other to minimize climatic variation.

At each site, an area 40 feet by 40 feet was divided into four square plots. Boundaries between plots were trenched to a 2-foot depth, so that the root systems were severed and prevented from transporting water across plot boundaries. Roofing paper was placed in the trenches to impede regrowth of the roots, and the trenches were refilled.

During July 1963, the oak was clearcut and removed from two of the plots at each site and a sprout stand was allowed to develop. A clearcut buffer strip 20 feet wide was established on the outer edges of the experimental area at each site. Thus the effects of 12 treatment combinations of aspect, elevation, and age of vegetation on water use by oak were compared. This arrangement provided for two replications of each combination.

To permit use of a neutron soil moisture probe, access tubing was installed to a 6-foot depth using a jackhammer-type drill. Two tubes were randomly located on each of the 24 plots, providing two soil moisture sampling points for each replication of the treatment combination. Measurements were made on all plots in early May, late July, and late September of 1964, 1965, and 1966.

A soil pit 6 feet deep was dug adjacent to each site, the profile was described, and samples were obtained from each horizon. Texture was determined by the Bouyoucos hydrometer method, organic matter content by wet digestion with chromic acid, and lime content by acid neutralization; moisture-holding properties were evaluated with a pressure membrane apparatus.

An analysis of variance was used to determine if differences in aspect and elevation of site and age of vegetation significantly affected soil moisture depletion. To detect any trends developing since treatment, a separate analysis was made of each year's data.

SOIL MOISTURE DEPLETION

The effects of differences in aspect and elevation of site, and age and density of vegetation on soil moisture depletion were tested during three growing seasons. Table 1 gives seasonal and total water losses for the various treatments, as well as the water loss--that is, the water loss that might be expected, calculated on the basis of the observed maximum differences between spring and fall readings, obtained during the 3 years.

Aspect.--During 1964 there was a significant difference in moisture depletion between the south aspect and the other two aspects. Between north and west aspects, differences in depletion were not statistically significant. A highly significant interaction was noted between aspect and elevation; most soil moisture was lost at 7,900 feet elevation on the south aspect, and least at 6,600 feet (table 1). In 1965, only minor differences were detected between aspects at either elevation; more precipitation occurred in this season, resulting in less soil moisture depletion. The differences among aspects were significant again in 1966, when the south aspect again had the greatest moisture depletion at 7,900 feet and the least at 6,600 feet. In that year, because of an exceptionally dry spring season, some of the available soil moisture evaporated on the south aspect at 6,600 feet before the early May readings.

Elevation.--During all 3 years, oak at the higher elevation extracted significantly more soil moisture than did the oak at the lower elevation (table 1). Two factors probably were largely responsible for the greater losses: (1) the oak was approximately 4 feet taller at the higher elevation and thus had a larger leaf area, and (2) the soils there were deeper and better developed and had greater moisture-holding capacity than soils at the 6,600 feet elevation.

Age of vegetation.--In 1964 the mature oak used considerably more soil moisture during the early part of the growing season but the moisture was rapidly depleted on the cut plots as soon as a vigorous sprout stand developed (table 1). Although the difference is not statistically significant, during that year approximately an inch more soil moisture was depleted under mature stands than under sprout stands. During 1965 little difference could be detected between age groups at 6,600 feet elevation, but the differences at 7,900 feet were great enough to make age of vegetation a statistically significant factor. Measurements during 1966 indicated a reversal in trend; sprout stands were now using significantly more moisture ($\frac{1}{2}$ to 1 inch more) than mature oak during the growing season.

Season of use.--Most soil moisture was depleted during the early part of the growing season (table 1). The surface 3 feet was essentially dry by the end of July. Late season moisture losses occurred mainly from the lower portions of the soil profile.

Depth of loss.--Oak, being a deeply rooted plant, is able to extract soil moisture from great depths. Little variation exists in the amount of moisture removed from the first 4 feet of the soil profile. At the 5- and 6-foot-depth levels there was somewhat less depletion. Most of the available moisture was removed from the entire 6 feet of soil by the end of each growing season.

Table 1. --Seasonal and total soil moisture depletion by Gambel oak during the growing season, according to plot treatment

Treatment	Seasonal losses (1964): May-July	Seasonal losses (1964): Aug-Sept	Total depletion: 1964	Total depletion: 1965	Total depletion: 1966	Maximum water losses[1]
	Inches					
6,600-FOOT ELEVATION						
North aspect						
Mature trees	8.33	2.09	10.42	6.29	8.44	11.09
Sprouts	7.19	3.40	10.59	6.60	10.32	12.26
South aspect						
Mature trees	7.85	0.44	8.29	5.86	4.16	9.00
Sprouts	7.25	0.37	7.62	6.72	4.03	8.53
West aspect						
Mature trees	7.84	1.90	9.74	5.58	9.67	10.70
Sprouts	6.49	3.07	9.56	5.19	10.49	11.42
7,900-FOOT ELEVATION						
North aspect						
Mature trees	8.86	2.89	11.75	9.46	8.74	12.19
Sprouts	7.55	3.06	10.61	6.44	8.87	11.45
South aspect						
Mature trees	8.23	4.73	12.96	8.87	10.12	14.28
Sprouts	5.58	5.90	11.48	7.42	12.43	14.79
West aspect						
Mature trees	8.67	1.42	10.09	8.71	8.03	11.06
Sprouts	7.69	1.53	9.22	7.13	7.04	10.27

[1] Based on maximum difference between spring and fall measurements using all 3 years' data.

EVAPOTRANSPIRATION

If deep seepage is negligible and no overland flow occurs, evapotranspirational loss can be estimated by adding growing season precipitation to soil moisture depletion. There was little difference in this sum between 1964 and 1966 when rainfall was comparable (table 2). In 1965, when rainfall was greater, the estimated evapotranspiration was also greater. There was less soil moisture depletion, but greater moisture loss from precipitation, resulting in as much as 5 inches' additional evapotranspiration during 1965. Summer precipitation generally occurs in small amounts at widely spaced intervals of time. Therefore, it is readily lost through poststorm evaporation from soils and plants and from transpiration of readily available surface soil moisture.

SOIL

The depth and quality of soil on the various sites was one of the major factors determining the amount of soil moisture depletion. The soils are high in clay content, which generally exceeds 35 percent (table 3). Silt content is generally near 30 percent in all profiles. Sand varies greatly from one profile and depth to another. Rocks are more prevalent at the lower elevations than at the upper, where few were observed in the surface 3 feet. On the south and north aspects at the lower elevation, stones greater than 4 inches in diameter were found distributed throughout the profile. Soils at the lower range of oakbrush are generally poorly developed, having a greater proportion of rocks and less clay than those at higher elevations. This may partially account for the lower moisture depletion observed at the lower elevations.

These soils developed from parent materials high in lime content. At the lower elevation, lime was only partially leached to shallow depths, and the subsurface soils here generally had more than 50 percent lime. At the upper elevation, a larger proportion of lime had leached from the surface soils, thus changing the pH and affecting the availability of plant nutrients. Although lime content is not directly related to water use, it does indicate the depth of soil development, which in turn is related to the amount of available moisture the soil can hold.

Organic matter content is directly related to the moisture-holding properties of the soil. Soils at the higher elevation had more organic matter extending to greater depths, a quality that was reflected in the higher moisture-holding capacities in their surface horizons. They held more available moisture and they also lost more moisture during the growing season than did those soils at the lower elevation. Organic matter content and texture are reflected in the values for 1/3- and 15-atmosphere moisture contents of soils. The difference between these percentages is the available soil moisture. The variation in the amount of available soil moisture from site to site affected the amount of moisture used by the oak at these various locations.

Table 2.--Evapotranspirational losses[1] during three growing seasons on various aspects, elevations, and ages of vegetation

Treatment	1964 Precip.	1964 ET	1965 Precip.	1965 ET	1966 Precip.	1966 ET
	Inches					
6,600-FOOT ELEVATION						
North aspect						
Mature trees	3.31	13.73	9.07	15.36	4.01	12.45
Sprouts		13.90		15.67		14.33
South aspect						
Mature trees	3.31	11.60	9.07	14.93	4.01	8.17
Sprouts		10.93		15.79		8.04
West aspect						
Mature trees	3.31	13.05	9.07	14.65	4.01	13.68
Sprouts		12.87		14.26		14.50
7,900-FOOT ELEVATION						
North aspect						
Mature trees	3.98	15.73	10.65	20.11	4.80	13.54
Sprouts		14.59		17.09		13.67
South aspect						
Mature trees	3.98	16.94	10.65	19.52	4.80	14.92
Sprouts		15.46		18.07		17.23
West aspect						
Mature trees	3.98	14.07	10.65	19.36	4.80	12.83
Sprouts		13.20		17.78		11.84

[1] Based on soil moisture depletion plus growing season precipitation.

Table 3.--Soil properties on six oakbrush sites in Ephraim Canyon

Aspect	Depth	Texture: Sand	Texture: Silt	Texture: Clay	Org. mat.	Lime	Moisture contents by weight: 1/3 Atm.	15 Atm.	Avail. H_2O
	Inches	Percent							
		6,600-FOOT ELEVATION							
North	0-13	23.9	28.4	47.7	3.38	11.4	30.27	16.92	13.35
	13-25	24.7	32.1	43.2	1.19	31.1	24.30	12.68	11.62
	25-40	42.3	6.0	51.7	0.51	40.0	19.91	7.48	12.43
	40-62	13.8	31.9	54.3	0.29	54.5	24.95	8.52	16.43
	62-72	33.0	28.9	38.1	0.23	16.5	34.29	17.08	17.21
South	0-8	38.9	28.2	32.9	6.36	23.3	24.66	13.61	11.05
	8-32	27.7	29.9	42.4	1.39	51.0	19.46	8.36	11.10
	36-72	25.4	32.0	42.6	1.39	53.0	22.45	8.90	13.55
West	0-9	27.6	35.2	37.2	3.50	23.5	25.42	14.38	11.04
	9-38	19.8	34.6	45.6	0.82	39.0	27.04	13.36	13.68
	38-45	20.0	43.6	36.4	0.49	14.5	32.38	7.16	25.22
	45-51	0.0	45.8	54.2	0.97	55.5	26.80	10.34	16.46
	51-72	2.7	52.5	44.8	0.45	55.0	19.84	8.65	11.19
		7,900-FOOT ELEVATION							
North	0-12	25.0	39.1	35.9	8.90	3.1	32.49	19.00	13.49
	12-20	24.8	32.5	42.7	5.95	2.8	31.56	18.72	12.84
	20-25	14.8	28.7	56.5	1.39	5.5	30.82	16.28	14.54
	25-34	12.4	30.9	56.7	1.33	45.0	25.40	11.84	13.56
	34-72	24.7	30.3	45.0	0.45	10.3	25.90	13.78	12.12
South	0-10	15.8	35.5	48.7	5.00	23.0	31.80	17.38	14.42
	10-27	23.5	29.4	47.1	5.84	27.0	27.08	15.79	11.29
	27-49	19.6	30.1	50.3	2.31	34.1	24.59	14.61	9.98
	49-72	25.0	30.0	45.0	1.78	50.5	26.27	11.85	14.42
West	0-11	19.8	38.4	41.8	5.20	2.9	26.88	15.99	10.89
	11-32	14.5	30.0	56.5	2.98	3.1	31.92	18.63	13.29
	32-44	26.0	26.2	47.8	0.66	19.5	24.48	13.15	11.33
	44-72	27.2	28.0	44.8	0.51	27.6	22.42	11.33	11.09

DISCUSSION

Differences in soil moisture depletion by oak were affected by aspect, elevation, and age of vegetation. Some of the variation caused by aspect and elevation can be attributed to differences in soil depth and quality. South aspects were most variable in moisture depletion, having high use rates at the upper elevational limits where soil and vegetation are conducive to large evapotranspirational losses. Less soil moisture depletion was observed at the lower elevation where soils generally are poorly developed and have less available moisture. Little difference was noted between north and west aspects.

If oak is cut and a vigorous sprout stand is allowed to develop, little saving in moisture can be expected after the first year, although the season of use is slightly affected. During the third growing season the sprout stands used more soil moisture than the mature stands.

To realize a substantial increase in the amount of soil moisture present at the end of the growing season, and therefore an increase in potential water yield from an area, a more severe treatment would have to be imposed than merely clearcutting oak and allowing resprouting. As long as the deep root systems are allowed to persist, soil moisture depletion by the sprouts will continue to be as great as from the original stand.

If deep-rooted oak is removed and shallow-rooted grass species established, considerable soil moisture depletion might be eliminated, especially from low in the profile where oak roots are able to extract much water. Treatments probably would be more effective at higher elevations where soils are better developed and more precipitation is received each year. South aspects appear to have the highest potential for depleting soil moisture. Vegetation conversion on these sites may considerably reduce the amount of loss occurring at lower depths, although an increased loss might occur from surface soil horizons. Additional information on soil moisture depletion by several grass species is needed for comparison with oak before treatment effects can be accurately predicted or specific treatments recommended.

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

U.S. Forest Service
Research Note INT-75

1968

NEW HERBICIDE KILLS NINEBARK

by

Dale R. Potter[1]

ABSTRACT

Ninebark can be killed with Tordon 22K or Tordon 101 with little danger to wildlife. Two spray coverages were found equally effective: foliage only and foliage-stem-root collar. No regrowth or sprouting occurred during three growing seasons.

Ninebark (Physocarpus malvaceus) decreases the utility of forest lands by severely restricting regeneration. Attempts to control this deep-rooted, perennial shrub with formulations of either 2,4-D or 2,4,5-T[2] have been unsuccessful. Tordon,[3] a more recently developed herbicide, is readily absorbed and translocated by leaves and roots of many broadleaved plants (1, 4, 6) and has generally been more effective than either 2,4-D or 2,4,5-T (3). Experiments begun during 1965 on the Boise Basin Experimental Forest in central Idaho show that Tordon effectively kills ninebark and prevents sprouting.

Tordon's high potency, even in minute quantities, requires that contact with desirable tree species, either through spray drift or soil containing the herbicide, should be avoided. Tordon may retain its potency in soil for several years (2). Pine, spruce, fir, maple, and cedar species in the Eastern United States have been killed or damaged by Tordon (6).

Birds, mammals, and fish show few or no ill effects from Tordon herbicide (5). Handling and application of the chemical are equally safe to the user if the manufacturer's instructions are followed closely.

In the present study, four north-facing plots were chosen at approximately 5,200 feet elevation. A plot contained 10 ninebark plants of uniform size, each of which was evaluated individually.

---

[1] Forest Research Technician stationed at Boise, Idaho.

[2] 2,4-dichlorophenoxyacetic acid and 2,4,5-trichlorophenoxyacetic acid, respectively.

[3] Dow Chemical Company trade name for picloram, 4-amino-3,5,6-trichloropicolinic acid. Trade names are used only for identification and no endorsement by the U.S. Forest Service is implied.

Two formulations of Tordon were used: Tordon 22K[4] and Tordon 101.[5] Two plots were treated with Tordon 22K, the other with Tordon 101.

Plots were sprayed in June of 1965. Both formulations were applied with a garden-type sprayer adjusted for low pressure.

Two forms of spray coverage were tested with each Tordon formulation: (a) broadcast spraying of foliage with wetting of stem and root collar, and (b) broadcast spraying of foliage only. Spray mixes consisted of 1 fluid ounce per gallon of water for Tordon 22K and 4 fluid ounces per gallon of water for Tordon 101.

Ninebark response to Tordon was evaluated 1 week after application and after one, two, and three growing seasons. The plant response rating system described by Dow Chemical Company was used (1).

Distortion, curling, and browning of ninebark leaf margins was noted 1 week after application. At the end of one growing season there was almost 100 percent browning and drying of foliage on all plots, regardless of spray formulation or spray coverage. Only one ninebark plant, sprayed with Tordon 22K on the foliage, stem, and root collar, had a single leaf with green coloring.

No regrowth or sprouting occurred during the three growing seasons. Based on these results the following conclusions are made:

1. Tordon 22K and Tordon 101 at prescribed application rates kill ninebark with little chance of sprouting;

2. Foliage sprays of either formulation are as effective as foliage-stem-root collar applications.

---

[4] 4-amino-3,5,6-trichloropicolinic acid as the potassium salt.

[5] 4-amino-3,5,6-trichloropicolinic acid as the triisopropanolamine salt and 2,4-dichlorophenoxyacetic acid as the triisopropanolamine salt.

LITERATURE CITED

(1) Gantz, R. L., and E. R. Laning, Jr.
1963. Tordon...for the control of woody rangeland species in the western United States. Down to Earth 19(3): 10-13.

(2) Goring, C. A. I., C. R. Youngson, and J. W. Hamaker.
1965. Tordon herbicide disappearance from soils. Down to Earth 20(4): 3-5.

(3) Hamaker, John W., Howard Johnston, Robert T. Martin, and Carl T. Redemann.
1963. A picolinic acid derivative: a plant growth regulator. Science 141 (3578): 363.

(4) Laning, E. R., Jr.
1963. Tordon...for the control of deep-rooted perennial herbaceous weeds in the western states. Down to Earth 19(1): 3-5.

(5) Lynn, G. E.
1965. A review of toxicological information on Tordon herbicides. Down to Earth 20(4): 6-8.

(6) Watson, A. J., and M. G. Wiltse.
1963. Tordon...for brush control of utility rights-of-way in the eastern United States. Down to Earth 19(1): 11-14.

Research Note

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

U.S. Forest Service
Research Note INT-76

1968

CABLE AND CLAMP MODIFICATIONS FOR MODEL 104 MOISTURE PROBES

Bland Z. Richardson[1]

ABSTRACT

Two Troxler depth moisture gages equipped with Model 104 probes being used in a hydrology study in the summer of 1963 were of little value because of repeated cable failure. Two modifications of the Model 104 probe, described herein, provided satisfactory service. A new clamp had to be developed for use with the cable.

Two Troxler depth moisture gages equipped with Model 104 probes were used by the Intermountain Forest and Range Experiment Station in a hydrology study in the summer of 1963. During the first 240 hours of operation, 200 hours were lost because of cable failure. In addition, continuity of records was so interrupted that collected data were of little or no value. The major source of trouble was broken strands of wire within the cable near the clamp or at the soldered connections within the plug. The breakage was caused by kinks in the wires within the rubber cable sheath that develop when the wires are flexed repeatedly during handling.

---

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

MODIFICATION OF PROBE

The Model 104 probe was modified to remove strain from the connecting plug and to limit flexing of the cable (fig. 1). The modification uses two brass adapters, a $3\frac{1}{2}$-inch brass nipple, and an 8-inch spring.

The strain was removed from the connecting plug by coupling the $3\frac{1}{2}$-inch brass nipple to the probe with one adapter and sealing with a rubber o-ring.

The flexing of the cable was restricted by using the other brass adapter as a compression nut. A rubber compression seal and a leather washer sealed this union. When tightened, this adapter secures the cable to the rubber sheath and limits movement of the cable strands. This adapter also serves as a spring retainer. The 8-inch spring, soldered to the adapter, limits the radius of cable bending for a distance of 1 foot (fig. 2).

After the Model 104 probe was modified, 400 to 600 moisture readings were recorded per day by using both units. By the end of the summer more than 15,000 readings had been recorded without a cable failure.

All parts used are available at any good hardware store, except brass adapter #3 and brass adapter #5 in figure 1. Both adapters can be manufactured at almost any machine shop. Total cost should not exceed $10.00.

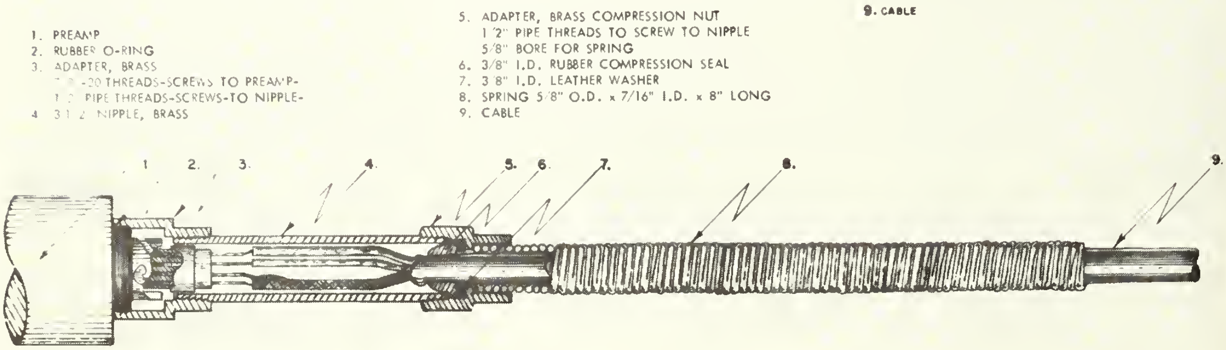


Figure 1.--Details of modification of cable connection for Model 104 depth moisture probes.

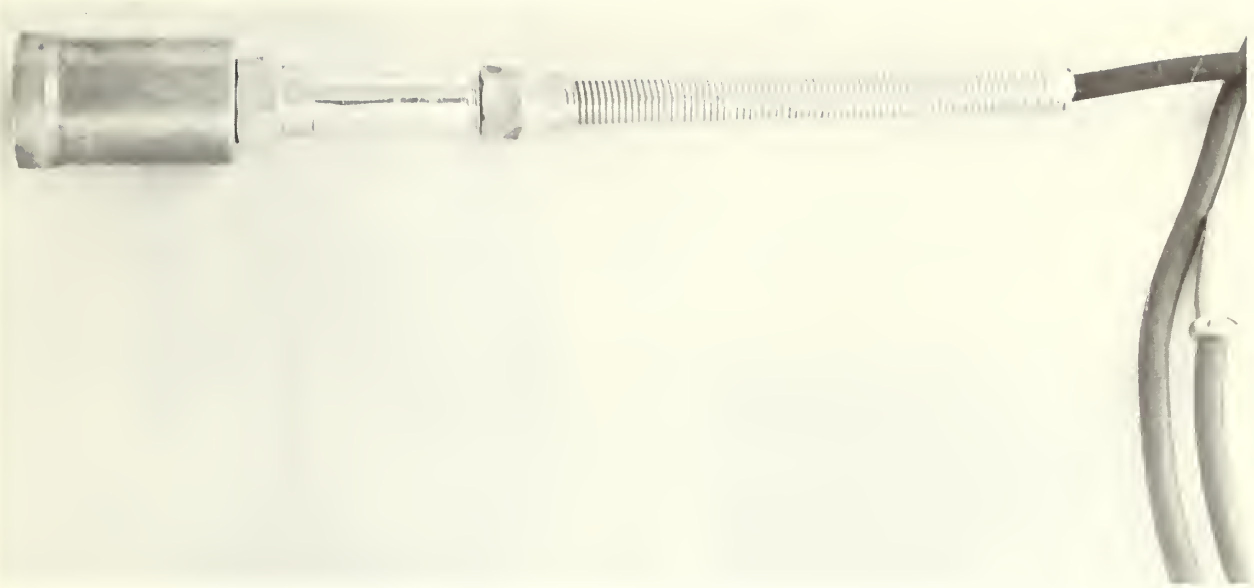


Figure 2.--Cable connection modification for Model 104 probes.

NEW CABLE CLAMP

Because this modification prevents the use of Troxler's existing clamps, a new cable clamp had to be developed (fig. 3).

The new clamp is spring-loaded to remain in the closed position. It can be opened to an intermediate position to permit passage of the cable and can be locked in a wide-open position to allow the previously described cable modification to pass through. To operate, a slight pressure applied to the ring on top of the clamp opens the clamp to the intermediate position and releases the probe cable. When pressure is removed, the clamp again locks the cable. To bring the probe into the standard, greater pressure is applied. This locks the clamp wide open and allows the modified portion of the cable to pass. Figure 4 shows the probe in a raised position.

The quick-release clamp can be made at a good machine shop and, although cost could vary greatly, it should not exceed $100.00. In quantity, it could be made at a much lower cost.

Figure 3.--Details of quick-release cable clamp showing internal mechanism.

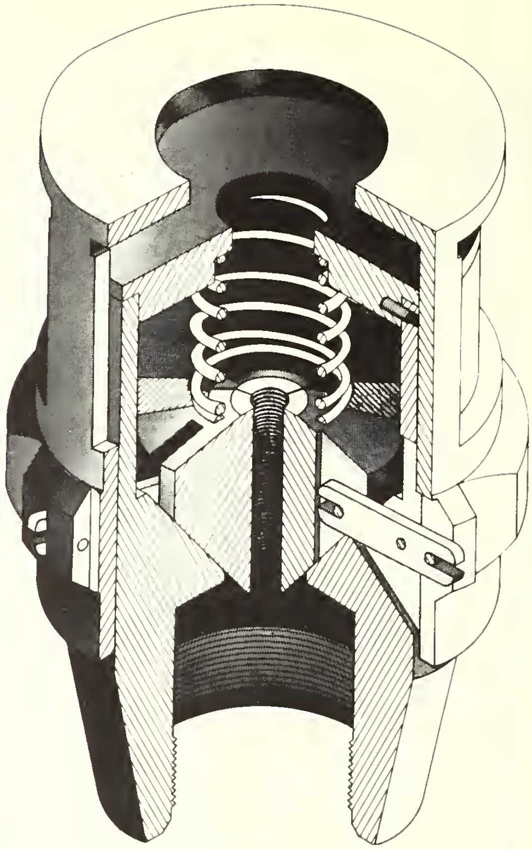


Figure 4.--Quick-release cable clamp installed on the shield and standard.

Research Note

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

U.S. Forest Service
Research Note INT-77 1968

A TREE-BY-TREE MEASURE OF SITE UTILIZATION FOR GRAND FIR RELATED TO STAND DENSITY INDEX

Albert R. Stage[1]

ABSTRACT

The usefulness of stand density index (SDI) has been limited by lack of a way to partition its nonlinear expression into additive components to describe the relative stocking of a stand by species or quality classes. In this paper, a linear equation is derived to permit such a partition.

A closely related expression for grand fir stocking is given that retains the merits of SDI, but is more nearly proportional to growth of individual trees within a stand. Hence, the partitioning of stocking into components will be more meaningful to the forest manager with this revised form.

One important use of a measure of stocking is to describe the relative composition of the growing stock according to species, quality, and size classes. However, interpretation of the measured composition depends on the units of measurement. In a related paper,[2] I have proposed that many aspects of stocking condition and control can be described in terms of greater management significance when stocking is measured in units proportional to site utilization. Site utilization can be measured from current growth data. However, when direct sampling of growth is not feasible, the silviculturist must fall back on some other way to measure stocking that approximates the distribution of growth among trees within the stand of interest. To be useful for describing composition, this alternative measure of stocking should be

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

[2]Stage, Albert R. A growth definition for stocking: units, sampling, and interpretation. (In preparation.)

additive, tree by tree, so that the total stocking for the stand will be the sum of its parts. The purpose of this Note is to describe an additive stocking measure for grand fir that is approximately proportional to growth.

Stand Density Index as proposed by Reineke[3] is a useful measure of stocking that relates the logarithm of number of trees per acre to the logarithm of tree size. The merits of this measure in contrast to polynomial measures of stocking such as basal area, tree-area ratio, and crown competition factor have been demonstrated by David Bruce.[4] He showed that the polynomial measures, throughout the range of their usefulness, are closely proportional to Stand Density Index. Furthermore, he argues that because Stand Density Index can be extrapolated to describe the effect of density on growth in stands as young as nursery seedlings, it must be the more generally valid form to use as an index of relative stocking.

A disadvantage of Stand Density Index is that there has been no way to describe the contribution of various classes of trees in the stand to the total index for the stand. The purpose of this Note is to demonstrate how this calculation can be accomplished, and to present a modified version of Stand Density Index for grand fir (Abies grandis (Dougl.) Lindl.).

COMPUTING STAND DENSITY INDEX TREE BY TREE

Stand Density Index as computed by Reineke is essentially

$$\log \mathrm{SDI} = \log N + k \log\left(\sum_{i=1}^{N} d_i^2/N\right)^{1/2} - k \qquad (1)$$

in which k is a constant equal to 1.605, N is number of trees per acre, and $(\Sigma\, d_i^2/N)^{1/2}$ is the diameter of the tree of average basal area. The index thus computed is stated in terms of number of trees per acre for a stand of 10 inches average d.b.h. In this form, the index is commonly used to compare densities from stand to stand.

Stand Density Index can be computed tree by tree within a stand. That is, the total SDI can be subdivided to represent the contribution to SDI of different classes of trees in the stand. The equation for SDI that is additive tree by tree is

$$\mathrm{SDI} = \sum_{i=1}^{N} (a + bd_i^2) \qquad (2)$$

or:

$$\mathrm{SDI} = Na + b\sum_{i=1}^{N} d_i^2$$

---

[3] Reineke, L. H. Perfecting a stand-density index for even-aged forests. J. Agr. Res. 46(7):627-638. 1933.

[4] Bruce, David. Unpublished paper presented at Lodgepole Pine Conference, Bend, Oregon. 1965.

where a and b are coefficients depending on the average diameter of all trees, and d_i is the diameter of the i^{th} tree in the tally. The coefficients are determined from the diameter of the tree of average basal area by the following equations:

$$a = 10^{-k} \left(1 - \frac{k}{2}\right) \left(\Sigma\, d_i^2/N\right)^{k/2}$$
$$b = 10^{-k} \left(\frac{k}{2}\right) \left(\Sigma\, d_i^2/N\right)^{(k/2)-1} \qquad (3)$$

Thus, if we have two classes of trees in a stand, the stocking of each component can be computed from equation (2) above by summing the values of $a + bd^2$ for the trees in each class. In turn, the total Stand Density Index will be the sum of the partial SDI's in each class.

A proof that substituting the coefficients a and b as defined in equation (3) into equation (2) yields an expression equivalent to (1) is given in the appendix to this Note.

APPLICATION TO GRAND FIR SITE UTILIZATION

Two modifications of SDI are here proposed for application to grand fir stands. First, for stands of a given average d.b.h., the index will be rescaled so that an index of 100 corresponds to the number of trees needed to fully utilize the site. Second, the form of the index within a stand will be changed from the form in equation (2) to be proportional to diameter cubed.

The reason for this latter change is to make the contributions to the per-acre stocking more nearly proportional to the growth of the individual trees. In even-aged stands of grand fir, growth per tree has been shown to be proportional to diameter cubed.[5] If growth is the criterion for rating contribution to stocking, the equation (2) for SDI given above overrates the smaller trees and underrates the larger trees.

Through analysis of growth data from study plots in even-aged grand fir stands,[5] the following expression was found to estimate the minimum number of trees per acre required to fully utilize a site capable of growing grand fir:

$$\log N = 4.26820 - 1.76235 \log \left(\sum_{i=1}^{N} d^3/N \right)^{1/3} \qquad (4)$$

This equation is clearly related to equation (1) for SDI given above. The principal difference is in the measure of average tree size. The cube root of the average of the cubed diameters has been substituted for the square root of the average of the squared diameters.

To emphasize the contribution of $\Sigma\, d^3$ in (4), consider this restatement of the same relation:

$$\log \Sigma\, d_i^3 = \log \left(\Sigma\, d_i^3/N\right)^{1-(k/3)} + 4.26820 \qquad (5)$$

[5]Stage, Albert R. A study of growth of grand fir (Abies grandis (Dougl.) Lindl.) in relation to site quality and stocking. Ph.D. Diss. Univ. Michigan, Ann Arbor. 1966.

in which $k = 1.76235$. Taking antilogs of (5) leads to

$$\Sigma d_i^3 = 18544. \ (\Sigma d_i^3/N)^{0.41255}$$

In this form, the right-hand side of this last expression gives the total sum of diameters cubed needed (per acre) to utilize the site completely at the stage of development given by $\Sigma d_i^3/N$, the mean of cubed diameters. Hence, the percent utilization of the site by trees can be expressed as

$$S = \frac{100 \ \Sigma d_i^3}{18544. \ (\Sigma d_i^3/N)^{0.41255}}$$

or, simplifying:

$$S = \frac{\Sigma d_i^3}{185.44 \ (\Sigma d_i^3/N)^{0.41255}}$$

Note that the denominator contains the average of cubed diameters over all trees in the stand. Table 1 lists the values of the denominator for stand diameters from 3 to 30 inches.

The sum in the numerator can then be separated into subtotals over those classes of trees in the stand for which stocking fractions are desired.

Obviously, it is very likely that stands will rate over 100 percent by this method, yet it is not possible to have the site more than fully utilized. The appropriate interpretation of a stocking index over 100, say, 125 percent, is that a fraction equal to 25/125 or 20 percent of the stocking could be removed, yet leave sufficient growing stock to fully utilize the site after sufficient time has passed to allow the remaining trees to adjust to the new level of stocking.

Site utilization of less than 100 percent could well be a desirable objective in young stands before any commercial thinning opportunities exist. In such stands, the value of more rapid diameter growth might well exceed the value of the unused site potential.

Example

Site utilization calculations for a sample tally from a fifth-acre plot in a young grand fir stand are illustrated in table 2. In this example, the site is apparently 99 percent utilized, about 48 percent of the growth capacity of the site being used by desirable trees.

Table 1.--Values useful in estimating stocking for grand fir.

Diameter	d^3	$185.44(\Sigma d_i^3/N)^{0.41255}$
3	27	722
4	64	1,031
5	125	1,359
6	216	1,703
7	343	2,061
8	512	2,432
9	729	2,813
10	1,000	3,205
11	1,331	3,606
12	1,728	4,016
13	2,197	4,435
14	2,744	4,861
15	3,375	5,294
16	4,096	5,734
17	4,913	6,181
18	5,832	6,634
19	6,859	7,093
20	8,000	7,558
21	9,291	8,029
22	10,648	8,504
23	12,167	8,986
24	13,824	9,471
25	15,625	9,962
26	17,576	10,458
27	19,683	10,958
28	21,952	11,462
29	24,389	11,971
30	27,000	12,484

Table 2.--Sample stocking calculations for a fifth-acre plot tally.

D.b.h.	Number of trees				Σd_i^3			
	Desirable	Acceptable	Cull	Total	Desirable	Acceptable	Cull	Total
3			11	11			297	297
4		15	9	24		960	576	1,536
5	13	20		33	1,625	2,500		4,125
6	30	40	4	74	6,480	8,640	864	15,984
7	18	5		23	6,174	1,715		7,889
8	2		2	4	1,024		1,024	2,048
Total	63	80	26	169	15,303	13,815	2,761	31,879

$$\Sigma d_i^3/N = 31879/169 = 188.6$$

$$185.44\ (\Sigma d_i^3/N)^{0.41255} = 1611$$ [1]

$$\text{Total } S = \frac{(31879)\ (5)}{1611} = 98.9\%$$

$$\text{Desirable } S = \frac{(15303)\ (5)}{1611} = 47.5\%$$

[1] Linear interpolation for $d^3 = 188.6$ in table 1 would have given $185.44\ (\Sigma d_i^3/N)^{0.41255}$ to be approximately 1599 instead of 1611. The effect of this difference on stocking interpretations would be negligible.

APPENDIX

PROOF OF TREE-BY-TREE EXPRESSION OF SDI

Equation (2), with coefficients a and b defined by equation (3) becomes

$$SDI = \sum_{i=1}^{N} (a + bd_i^2) = Na + b\sum_{i=1}^{N} d_i^2$$

$$= 10^{-k} (1 - k/2) \left(\sum_{i=1}^{N} d^2/N\right)^{k/2} N$$

$$+ 10^{-k} (k/2) \left(\sum_{i=1}^{N} d^2/N\right)^{(k/2)-1} \left(\sum_{i=1}^{N} d_i^2\right)$$

Hence

$$SDI = 10^{-k} \left[(1 - k/2) \left(\sum_{i=1}^{N} d^2\right)^{k/2} N^{1 - k/2}\right.$$

$$\left. + (k/2) (N^{1 - k/2}) \left(\sum_{i=1}^{N} d_i^2\right)^{k/2}\right]$$

$$= 10^{-k} \left(\sum_{i=1}^{N} d_i\right)^{k/2} N^{1 - k/2}$$

Taking logarithms to base 10

$$\log SDI = -k + k/2 \log \left(\sum_{i=1}^{N} d_i^2\right) + (1 - k/2) \log N$$

$$\log SDI = k/2 (\log \sum_{i=1}^{N} d_i^2 - \log N) + \log N - k$$

$$\log SDI = \log N + k \log (\Sigma d_i^2/N)^{1/2} - k$$

This last equation is identical with (1) which was to be proven.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

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

U.S.D.A. Forest Service
Research Note INT-78

1968

PROPERTIES OF SOIL UNDER ASPEN AND HERB-SHRUB COVER

Ronald K. Tew[1]

ABSTRACT

Several physical and chemical soil properties were measured and related to site aspect and vegetation type. Soil texture, aggregation, organic matter content, nitrate production, and moisture-holding characteristics varied between aspects. Soils under aspen stands have higher organic matter content, with accompanying higher moisture-holding capacity, than do soils on adjacent herb-shrub sites.

The physical and chemical properties of soils are partially determined by the vegetation they support; conversely, the type and amount of vegetation depend on the soil productivity. The exact nature of these relations has not been clarified on most wildland soils, but there is great need for such information as a basis for management decisions.

Changes in soil characteristics are apt to occur when water yield improvement measures are applied to our mountain lands, especially when such measures include the manipulation of vegetation. The influence of these changes on soil stability, productivity, and water-holding characteristics becomes of utmost interest. Several differences between soils under aspen and on adjacent sites covered with herbs and shrubs, on each of four aspects, have been evaluated. They show possible soil changes that might be expected if a type conversion were attempted.

METHODS

Soil samples were collected in the vicinity of Logan Canyon in northern Utah. Only the surface 6 inches was sampled, as this is the zone of major biological activity and would be most influenced by management practices. Also, the vegetation occupying the site would be most influential in modifying soil properties in this zone. Paired soil samples (one from aspen, the other from adjacent herb-shrub cover) were collected from 48 random locations ranging in elevation from 6,500 to 8,500 feet. Twelve pairs of

---

[1] Associate Plant Physiologist, stationed in Logan, Utah, at the Forestry Sciences Laboratory, which is maintained in cooperation with Utah State University.

samples were obtained on each aspect--north, south, east, and west--making a total of 96 samples. Each sample was a composite of four subsamples. All soils were taken to the laboratory, passed through a 2-mm. sieve, and analyzed.

Texture and aggregation were determined by hydrometer methods. An acid neutralization technique was used for the lime determinations, and organic matter was determined by a chromic acid oxidation procedure. Moisture relations were evaluated with a pressure membrane apparatus. Available phosphorus was extracted from the soil with a 0.5N sodium bicarbonate solution and measured colorimetrically. The pH was measured on a Beckman Model 12 pH meter[2] using a saturated soil paste. The nitrogen-supplying capacity was evaluated by measuring the amount of nitrate produced in a moist 10-gram soil sample during a 2-week incubation period at 35°C.

RESULTS

All aspen sites sampled had a mature stand of vigorous trees averaging between 5 and 6 inches in diameter. The herb-shrub sites were occupied by big sagebrush (*Artemisia tridentata* Nutt.), rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.), snowberry (*Symphoricarpos vaccinoides* Rydb.), yarrow (*Achillea lanulosa* Nutt.), horsemint (*Agastache urticifolia* (Benth.) Kuntze), tall butterweed (*Senecio serra* Hook.), and several grass species. On all sites similar species were present, but there were variations in cover density and percentage composition. Table 1 provides a summary of the measured soil properties, each value representing an average of 12 samples.

Texture and aggregation.--The majority of the soils tested were loams. Silt content was similar on all aspects and vegetation types. Aspen sites were higher in sand and lower in clay than the adjacent herb-shrub sites. South aspects were lowest in clay and highest in sand. These variations in texture were reflected in the quantity of water-stable aggregates present.

Aggregation was lowest on south aspects regardless of vegetation type. This property was found to be directly related to the clay and organic matter content. An equation was developed to correlate the various soil properties, as follows:

$$Y = 11.64 + 1.692X_1 - 0.0036X_1^2 + 0.649X_2$$

where Y is the percent aggregation, X_1 represents the percent clay, and X_2 the percent organic matter.

A multiple correlation coefficient of 0.88 indicated that a good relation existed. This equation would apply only under the conditions tested, however.

No significant difference in aggregation was observed between vegetation types. Soil under aspen contained more organic matter but less clay, so that the factors affecting aggregation were balanced.

Lime content and pH.--In general, pH was greater on aspen sites than on adjacent herb-shrub sites. The difference was usually from 0.1 to 0.2 pH unit. The range in pH for all samples was from 5.8 to 6.8, and most were near 6.2. A greater range in pH would have been expected if subsoils had also been sampled.

The calcium carbonate equivalent (or lime) in these soils was closely related to pH. Aspen sites had slightly greater lime content than adjacent sites. Differences due to aspect were insignificant. Differences in both pH and lime content were statistically significant at the 5-percent level.

[2] Trade names are used herein for identification and do not imply endorsement by U.S.D.A. Forest Service.

Table 1.--Summary of soil properties

Vegetation type;aspect	Sand	Silt	Clay	Aggreg.	Organic matter	Lime	1/3 atm.	15 atm.	Avail. H_2O	Particle density	Available phosphorus[1]	Ppm[2] NO_3	pH
	- - -	- - -	- - -	- - -	- - -	- - -	-Percent-	- - -	- - -	- - -	- - -	- - -	- - -
Aspen:													
North	37.1	42.7	20.2	55.7	10.6	1.62	33.9	16.5	17.4	2.49	260	33.9	6.16
South	43.2	41.0	15.8	42.4	10.2	1.43	30.2	13.3	16.9	2.49	258	64.9	6.32
East	37.7	41.2	21.1	54.1	12.3	1.77	35.8	17.4	18.4	2.47	267	45.9	6.24
West	34.7	43.4	21.9	58.9	10.3	1.49	33.6	16.1	17.5	2.49	265	42.6	6.17
Average	38.1	42.1	19.8	52.8	10.9	1.58	33.4	15.8	17.6	2.49	263	46.8	6.22
Herb-shrub:													
North	31.6	43.9	24.5	55.4	7.7	1.32	29.9	13.6	16.3	2.53	219	60.4	6.06
South	41.3	40.9	17.8	42.0	6.5	0.98	24.0	9.8	14.2	2.53	212	56.0	6.11
East	31.5	42.1	26.4	55.8	6.6	1.40	29.4	13.9	15.5	2.54	207	58.7	6.09
West	32.1	43.3	24.6	50.9	7.3	1.38	28.9	14.2	14.7	2.54	207	55.5	6.14
Average	34.1	42.6	23.3	51.0	7.0	1.27	28.1	12.9	15.2	2.54	211	57.7	6.10

[1] Expressed in pounds of P_2O_5 per acre 6 inches.
[2] As produced in moist soil samples incubated 2 weeks at 35°C.

Organic matter content.--A large difference was observed between vegetation types, aspen sites having approximately 4 percent more organic matter. South aspect sites had slightly less organic matter than the other aspects tested. The importance of these differences becomes evident when other physical and chemical properties of the soil are considered.

Particle density.--Equations were developed for both vegetation types to relate particle density of the soil to the organic matter content. It was assumed that parent material was similar, as the same Y intercept was found for both vegetation types; therefore, all data were combined into a single equation:

$$Y = 2.63 - 0.0134X$$

where Y is particle density and X is orgnanic matter content.

A correlation coefficient of 0.88 indicated that a good relation existed. Estimates of either particle density or organic matter content could be obtained from such an equation if the concomitant variable were known. Particle density estimates would be useful when porosity determinations are desired.

1/3-and 15-atmosphere percentages.--Close relations existed between the moisture measurements and the amount of clay and organic matter present. A multiple regression analysis using these two factors and either 1/3- or 15-atmosphere percentages as the dependent variable gave correlation coefficients of 0.866 for the 1/3- and 0.929 for the 15-atmosphere percentages. The difference between 1/3- and 15-atmosphere percentages is an estimate of available moisture for the appropriate horizon. On all aspects, the 1/3- and 15-atmosphere percentages were higher on aspen sites than on adjacent areas. Although 1/3-atmosphere percentages were approximately 5 percent higher on aspen sites, the 15-atmosphere percentages were also higher, so that differences in available moisture between vegetation types were only 2 to 3 percent. South aspects had 1 to 2 percent less available moisture than the other aspects.

Fertility status.--No single soil property measured could be directly related to the rate of nitrification. Nitrate production was generally highest on the herb-shrub sites, all aspects being similar. Aspen sites were more variable; nitrate production was highest on south aspects and lowest on north aspects.

Phosphorus availability was greater on aspen sites than on adjacent areas for all aspects. No difference was noted between aspects on either vegetation type.

DISCUSSION

Many soil properties were different under aspen and adjacent vegetation types, at least in the surface 6 inches. These soil differences were probably related to the vegetation type, since climate and topography were similar on paired sites. Also, particle densities were identical under the two vegetation types when compared on an organic-matter-free basis; therefore, the soils were apparently developed from the same parent material. The differences observed in the soil properties under the two vegetation types are corroborated by McKeague and Bentley (1960), who found that aspen leaves altered redox potentials, which in turn influenced soil development.[3]

Although texture was not equivalent on the two vegetation types, the differences were probably small enough to ignore in regard to the initial establishment of aspen on any particular site. The fact that aspen was growing on soils covering a wide range in texture seems to justify this conclusion.

If aspen were removed, we could expect a decrease in the organic matter content of the soil. Decreases in moisture-holding capacity, aggregation, and porosity would probably follow the organic matter reduction. Phosphorus availability might also decline.

Results from the pH and lime determinations indicate cycling of bases has been more active under aspen than on adjacent sites. This is important in control of the quantity of nutrients available. As indicated by the levels of nitrification resulting from laboratory tests, several plants would probably show a significant response to nitrogen applications on both vegetation types if moisture was not a limiting factor. All sites appeared to be high in available phosphorus, but additional information relating plant response to experimental results would be desirable before any conclusions were made about phosphorus responses. Until such information is obtained, the differences observed between vegetation types serve only for comparison.

Aspect as well as vegetation type is important in determining soil quality. Aggregation and moisture-holding properties were poorest on south aspects, where soils were coarse textured. Lime content, pH, particle density, and phosphorus availability were similar on all sites. Results indicate that aspect is important from the standpoint of species adaptability and water-holding capabilities. Soils having poor aggregation, such as on the south aspects, would be more unstable and susceptible to erosion and would require more careful management than soils on other aspects.

Removal of aspen and its replacement with another vegetation type will probably cause some changes in the underlying soil. The cited soil differences existing between established aspen sites and adjacent herb-shrub sites point up some of the probable long-term changes to be expected if aspen were converted. Some changes may occur in a few years; others may require decades or even a century.

---

[3]McKeague, J. A., and C. F. Bentley. The effect of drainage condition on the redox potential, leachate composition and morphological characteristics of a soil parent material studied in the laboratory. Can. J. Soil Sci. 40(2): 121-129. 1960.

Research Note

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

U.S.D.A. Forest Service
Research Note INT-79 1968

COMPUTER PROGRAMS FOR WEIGHTING LENGTH-OF-STAY AND OTHER VISITOR CHARACTERISTICS

J. Alan Wagar and Joel F. Thalheimer[1]

ABSTRACT

When recreationists of different characteristics have different probabilities of being included in recreation surveys, the resulting averages for these characteristics can be severely biased unless special computational procedures are used. This paper describes the use of two computer programs for correcting biases that would otherwise result from (a) differences in length of stay, (b) known probabilities for sampling each individual, or (c) the combined effects of a and b.

If visitors of different ages, incomes, education levels, and other characteristics have different probabilities of being sampled in a recreation survey, results can give strongly biased averages unless special computational procedures are used. Both length of stay and sampling design can affect the probability of including each visitor in the sample.

As Lucas pointed out, visitors who stay a long time are much more likely to be sampled than those who stay only a short time (3, 4).[2] As a result, the characteristics associated with long stays are overrepresented in the data and characteristics associated with short stays are underrepresented. Also, if different recreation sites are sampled at different intensities, the characteristics of visitors on the more heavily sampled sites would be overrepresented in the data. However, Lucas showed that averages for visitor characteristics can be computed without bias from survey data if each observation is weighted by the inverse of its probability of being included in the sample.

---

[1]The senior author formerly was Leader of the Cooperative Recreation Research project maintained by the Intermountain Forest and Range Exp. Station, Forest Service, U.S. Department of Agriculture, in cooperation with Utah State University at Logan; and the junior author was a graduate student in the Department of Forest Science at the same University. Wagar is now Leader of the Cooperative Recreation Research project maintained by the Pacific Northwest Forest and Range Exp. Station in cooperation with the University of Washington at Seattle; and the junior author is now owner-manager of a resort in Arizona.

[2]Numbers in parentheses refer to Bibliography.

The extent of possible bias is shown by a study of fisherman use at Flaming Gorge Reservoir in Utah and Wyoming (2). Unweighted estimates of average length of stay were from 2.60 to 3.44 times as large as estimates that were weighted to correct for the probability of including each person in the sample.

Visitor characteristics related to length of stay could also be overestimated from unweighted survey data. For example, an individual's expenditures usually depend on how long he stays, and average expenditures per person could therefore be grossly overestimated from unweighted survey data.

Similar problems could occur in estimates of age, income, education, and other visitor characteristics. For example, if retired people tended to stay longer on a recreation site than people from other age groups, the average age of visitors could be substantially overestimated from unweighted data.

Deming provided procedures not only for obtaining weighted averages but also for computing the variances for such averages (1). The following formulae are based on these procedures:

$$\text{Weighted mean} = \bar{X}_w = \frac{\Sigma w_i X_i}{\Sigma w_i}$$

$$\text{Variance of the mean} = S_{\bar{X}}^2 = \frac{\Sigma\left(w_i X_i^2\right) - \bar{X}_w^2 \, \Sigma w_i}{\Sigma w_i \,(n - 1)}$$

where:

w_i is the weighting factor for individual i. This is the inverse of the individual's probability of being included in the sample.

X_i is an observation or measurement of a variable for individual i.

n is the number of individuals in the sample.

These weighting procedures have been incorporated into two short computer programs that permit rapid processing of data suited to any of seven different weighting schemes. In these programs, up to 10 variables (characteristics) per sampled individual can be weighted by the inverse of (a) length of stay, (b) a known sampling probability, or (c) the combined effects of (a) and (b). With very slight modification, the programs will readily handle additional variables for each sampled individual. A weighted mean and variance are then computed and printed for each variable (labeled as "datum" in the printed output). The programs also compute and print a weighted mean and variance for length of stay.

PROGRAM 1

For flexibility, six sampling schemes (A to F) are provided in Program 1 and can be selected to suit various sampling situations. Schemes A, B, and C correct only for length of stay.

For Scheme A, the smallest unit of time recognized is a day, and each observation is corrected for the number of days an individual is present. This scheme would be appropriate for an area that is sampled (a) during the hours people normally arrive and depart and (b) on each of a random selection of days. Scheme A requires a minimum amount of detail in the data, and the output includes a weighted mean and variance for the days on which a visitor is actually present. (This is not quite equivalent to length of stay in days but is a close approximation.) Sample results are given in figure 1.

```
TEST RUN FOR PROGRAM 1, SCHEME A OR D

NUMBER OF SAMPLES  =    10.

WEIGHTED AVERAGE, DAYS PRESENT  =     3.1683
VARIANCE FOR LENGTH OF STAY  =      9.5161

WEIGHTED AVERAGE FOR DATUM  1  =  42.4583
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  1  =     756.5978

WEIGHTED AVERAGE FOR DATUM  2  =     2.4979
WEIGHTED VARIANCE OF THE MEAN FOR DATUM   2 =       1.2085

WEIGHTED AVERAGE FOR DATUM  3  =    7.0351
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  3  =       3.0713

WEIGHTED AVERAGE FOR DATUM  4  =  39.1554
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  4  =     127.4493

WEIGHTED AVERAGE FOR DATUM  5  =  42.9808
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  5  =      32.3951
```

Figure 1.--Simulated sample printout for Program 1 showing results as provided by Schemes A and D.

In Scheme B, a sampling period is defined to include the same hours of each sampled day. For example, campers might be sampled between 2000 and 2200 hours in the evening on a random selection of sample days; thus for weighting, each observation is corrected for the number of 2000-to-2200 periods during which an individual is present. To simplify the data and computations, all times are given on a 24-hour basis. Thus 1100 is 11 a.m., 1200 is 12 noon, 1300 is 1 p.m. ... and so forth.

Scheme B also computes the actual number of on-the-hour times during which each sampled individual is present. Thus a person arriving at 1510 and leaving at 2150 would be present for six on-the-hour times--1600 through 2100. As shown in figure 2, the weighted average for hours present is printed out along with its variance.

In Scheme C, sampling takes place on single on-the-hour times selected at random within specified limits. For example, sampling on a recreation site might be specified for each of 20 on-the-hour times selected at random between the hours of 0900 and 2100 on any day between May 30 and September 6. In this scheme, each observation would be weighted to correct for the number of on-the-hour times an individual is present during which sampling could take place. Thus, if he arrived at 1630 one day and left at 0930 the next, he would be present for the six on-the-hour sampling times--1700 through 2100 and 0900. As in Scheme B, the average and variance for hours present are printed in Scheme C, as illustrated in figure 2.

Schemes D, E, and F of Program 1 are designed to handle situations where it is desirable to weight sample data to correct for known sampling probabilities in addition to the probabilities created by length of stay.

```
TEST RUN FOR PROGRAM 1, SCHEME B, C, E, OR F.

NUMBER OF SAMPLES  =    10.

WEIGHTED AVERAGE, HOURS PRESENT  =    11.1536
VARIANCE FOR LENGTH OF STAY  =     862.7324

WEIGHTED AVERAGE FOR DATUM  1  =    12.1405
WEIGHTED VARIANCE OF THE MEAN FOR DATUM   1  =     134.9237

WEIGHTED AVERAGE FOR DATUM  2  =     1.0292
WEIGHTED VARIANCE OF THE MEAN FOR DATUM   2  =       0.3976

WEIGHTED AVERAGE FOR DATUM  3  =     4.6906
WEIGHTED VARIANCE OF THE MEAN FOR DATUM   3  =       1.3208
```

Figure 2.--Simulated sample printout for Program 1 showing results as provided by Schemes B, C, E, and F.

For example, it might be convenient to sample large recreation areas more often than small recreation areas while still correcting for length-of-stay bias. In this case the characteristics of each sampled individual would need to be weighted for both the probability of sampling a given recreation site and the probability of including an individual in the sample at the site selected. Therefore w_i in Deming's formulae becomes the inverse of the product of two sampling probabilities. With minor modification, Program 1 would readily handle additional probabilities. The weighting factor would simply be the inverse of the product of three or more probabilities.

Scheme D is equivalent to Scheme A except that weighting corrects for known sampling probabilities in addition to the number of days in which each sampled individual is present. In the same manner, Scheme E is a modification of Scheme B and Scheme F is a modification of Scheme C. Scheme E weights for known probabilities in addition to the number of sampling periods during which a sampled individual is present. Scheme F weights for known probabilities in addition to the number of on-the-hour times an individual is present during which he could be sampled. Figure 2 also illustrates the form of output resulting from Schemes D, E, and F.

PROGRAM 2

Program 2 is a simplification of Program 1 designed for data in which the probability of each individual's being sampled is already known and can be entered directly with the rest of the sample data. For example, if a survey is made of visitors leaving a recreation area at various road exits, it might be desirable to sample heavily used exits on 10 percent of the days in a use season and lightly used exits on only 5 percent of the days. In this kind of survey, length of stay would not affect sampling probabilities. Thus the probability of sampling each person leaving by a heavily used exit would be 0.10 and the probability of sampling each person leaving by a lightly used exit would be 0.05. Figure 3 shows a sample output for Program 2.

```
TEST RUN FOR PROGRAM 2.

NUMBER OF SAMPLES  =     5.

WEIGHTED AVERAGE FOR SAMPLING PROBABILITIES  =     2.6592
VARIANCE FOR SAMPLING PROBABILITIES  =    11.1292

WEIGHTED AVERAGE FOR DATUM  1  =    11.0123
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  1  =     39.8680

WEIGHTED AVERAGE FOR DATUM  2  =    67.7673
WEIGHTED VARIANCE OF THE MEAN FOR DATUM  2  =    250.5530
```

Figure 3.--Simulated sample printout for Program 2.

PROGRAM CHARACTERISTICS

Programs 1 and 2 were written in FORTRAN IV for a Control Data Corporation 3200 Computer and were then adapted to an IBM 7094.[3] However, they can be adapted to almost any computer with a FORTRAN IV compiler. Because few data are held in memory at any one time, little storage is needed beyond that required for storing the program itself.

Variable names have been used to indicate the card reader (IZIN) and the printer (IZOUT). As a result, the programs will fit many computers immediately if IZIN is set equal to the number designating the card reader and IZOUT is set equal to the number designating printer.

[3] Trade names are used herein solely for identification and do not imply endorsement by the U.S.D.A. Forest Service.

INSTRUCTIONS FOR PROGRAM USE

Program 1

The first three data cards of Program 1 read in (a) the days to the beginning of each month, (b) a label for whatever job is being run, and (c) the values of J, B, E, Q, and QW. For all data that do not include the date February 29, the first card will be punched 000031059090...334 in columns 1 to 36, indicating that 000 days in the year have passed at the beginning of January, 031 days have passed at the beginning of February, 059 at the beginning of March, 090 at the beginning of April, etc., to 334 at the beginning of December. For data that include February 29, this card would be replaced by one reading 000031060091...335. Program 1 will handle data that extend from one year to the next, provided that no more than 365 days are included.

The second data card can have any combination of letters and numbers. This is used for a label of up to 80 characters and spaces that identifies the job being run.

The third data card specifies values of J, B, E, Q, and QW in columns 7-8, 9-10, 11-12, 13-14, and 15-16, respectively. Variable J is set equal to the number of variables to be weighted for each sampled individual (from 01 to 10); B specifies the earliest hour that sampling can occur (01 to 24); and E specifies the latest hour that sampling can occur (01 to 24). The variables Q and QW are selected to specify computations appropriate to the various sampling schemes. Thus if QW is set equal to +1, setting the variable Q equal to -1, 00, or +1 will specify computations for Scheme A, B, or C, respectively. If QW is set equal to zero, then setting the variable Q equal to -1, 00, or +1 will specify computations for Scheme D, E, or F, respectively.

Table 1 summarizes the characteristics of sampling Schemes A to F and coding for the third data card used with Program 1.

After the first three data cards, an additional data card is used for each sampled individual. Each of these cards specifies time of arrival, time of departure, and values for up to 10 variables. For Schemes D, E, and F, each card must also specify a known sampling probability (P).

In Schemes B, C, E, and F, arrival and departure times are coded as 6-digit numbers. The first two digits specify month (F1 for arrival, AL1 for departure), the second two digits specify day of month (F2 for arrival, AL2 for departure), and the third two digits specify hour (F3 for arrival, AL3 for departure). The hour of arrival is recorded as the first on-the-hour time a visitor is present, and the hour of departure is recorded as the last on-the-hour time a visitor is present. Thus an arrival time of 1410 would be coded as 15, a departure time of 0945 as 09, etc.

Program statements 3 and 4 can be rewritten to read data in whatever format is desired. For example, the hour of arrival (F3) and the hour of departure (AL3) are not needed for Schemes A and D, and program statements 3 and 4 could be simplified to delete these variables.

For all six sampling schemes in Program 1, a blank card is placed after the last data card. This causes the program to go on to the remaining computations and then stop.

If all data are to be handled according to Scheme A or D, Program 1 can be shortened by deleting all program statements preceded by X and by changing the statement preceding Statement 6 from GO TO 8 to GO TO 34. For this shortened program, the value of J must still be entered in columns 7-8 and the value of QW entered in columns 15-16 of the third data card, but values of B, E, and Q are not used. Further simplification of Program 1 results in Program 2.

Table 1.--Summary of characteristics for Sampling Schemes A to F of Program 1 and of the coding for the third data card used with this program

Sampling scheme	Weights for:	Coding for 3rd data card				
		J	B	E	Q	QW
A	length of stay as days present	number of observations per sampled individual	not used	not used	-1	+1
B	length of stay as sampling periods present	ditto	1st hour on which sampling can take place	last hour on which sampling can take place	00	+1
C	length of stay as on-the-hour sampling times present	ditto	ditto	ditto	+1	+1
D	length of stay (as days) plus known sampling probability	ditto	not used	not used	-1	00
E	length of stay (as sampling periods) plus known sampling probability	ditto	1st hour on which sampling can take place	last hour on which sampling can take place	00	00
F	length of stay (as hours) plus known sampling probability	ditto	ditto	ditto	+1	00

Program 2

Application of Program 2 is similar and somewhat simplified from application of Program 1. No data card is used to specify days to the first of each month so the first data card is the one used to provide a label of up to 80 characters and spaces. Following this, one card is used for each sampled individual to give the sampling probability (P) and up to 10 variables for that individual. As before, a blank card is used at the end of the data to direct the computer to remaining computations and then to a stop.

PROGRAM 1 -- PAGE 1

```
      DIMENSION X(10),SWIZI(10),VARP(10),A(12),ID(20)
      IZIN=5
      IZOUT=6
C   IZIN=CARD READER.  IZOUT=PRINTER
      READ(IZIN,25) (A(L),L=1,12)
   25 FORMAT(12F3.0)
      READ(IZIN,100)(ID(I),I=1,20)
  100 FORMAT (20A4)
      WRITE(IZOUT,101)(ID(I),I=1,20)
  101 FORMAT(1H1,20A4)
   52 READ(IZIN,32) J,B,E,Q,QW
   32 FORMAT( 6X,I2,4F2.0)
      Z=0.
      SWIZ=0.
      VARPZ=0.
      SWIJ=0.
      DO 5K=1,J
      SWIZI(K)=0.
    5 VARP(K)=0.
  3   READ(IZIN,4)P,F1,F2,F3,AL1,AL2,AL3,(X(I),I=1,J)
  4   FORMAT(6X,F4.3,6F2.0,10F5.2)
      IF(F1+AL1)19,18,19
   19 IF (F1-AL1)23,6,26
   26 AL2=AL2+365.
   23 L=F1
      FF=A(L)+F2
      L=AL1
      FFF=A(L)+AL2
      T=FFF-FF+1.
      GO TO 8
    6 T=AL2-F2+1.
X   8 IF(Q) 34,1,1
X   1 IF(1.+E-F3)9,9,40
X  40 IF(Q) 41,41,10
X  41 AF3=1.+E-B
X     GO TO 11
X  10  IF(B-F3)42,42,43
X  42 AF3=1.+E-F3
X     GO TO 11
X  43 AF3=1.+E-B
X     GO TO 11
X   9 AF3=0.
X  11 IF(AL3-B+1.)12,12,44
X  12 AL3A=0.
X     GO TO 16
X  44 IF(Q) 15,15,13
X  13  IF(AL3-E)14,14,15
X  14 AL3A=AL3-B+1.
X     GO TO 16
X  15 AL3A=E-B+1.
X     GO TO 16
   34 WIJ=1./T
      ZI=T
X     GO TO 35
X  16 WIJ=1./(AF3+AL3A+((T-2.)*(E-B+1.)))
```

```
          ZI=25.-F3+AL3+((T-2.)*24.)
     35   IF(QW)61,60,61
     60   WIJ=WIJ/P
     61   DO 17 K=1,J
          SWIZI(K)=WIJ*X(K)+SWIZI(K)
       17 VARP(K)=WIJ*(X(K)**2)+VARP(K)
          SWIJ=WIJ+SWIJ
          SWIZ=WIJ*ZI+SWIZ
          VARPZ=WIJ*(ZI**2)+VARPZ
          Z=Z+1.
          GO TO 3
      18  WRITE(IZOUT,21) Z
       21 FORMAT(21HONUMBER OF SAMPLES = F7.0)
          SWIZ=SWIZ/SWIJ
          VARPZ=(VARPZ-((SWIZ**2)*SWIJ))/((Z-1.)*SWIJ)
X         IF(Q)36,37,37
      36  WRITE(IZOUT,38)SWIZ
       38 FORMAT(35HOWEIGHTED AVERAGE, DAYS PRESENT  = F10.4)
X         GO TO 39
X     37  WRITE(IZOUT,31)SWIZ
X      31 FORMAT(35HOWEIGHTED AVERAGE, HOURS PRESENT = F10.4)
      39  WRITE(IZOUT,33) VARPZ
       33 FORMAT(31H VARIANCE FOR LENGTH OF STAY = F12.4)
          DO20K=1,J
          SWIZI(K)=SWIZI(K)/SWIJ
          VARP(K)=(VARP(K)-((SWIZI(K)**2)*SWIJ))/((Z-1.)*SWIJ)
          WRITE(IZOUT,22)K,SWIZI(K)
       22 FORMAT(28HOWEIGHTED AVERAGE FOR DATUM I2,3H = F10.4)
      20  WRITE(IZOUT,30)K,VARP(K)
       30 FORMAT(41H WEIGHTED VARIANCE OF THE MEAN FOR DATUM I2,3H = F12.4)
          READ(IZIN,50)INT
      50  FORMAT(I6)
          IF(INT-999999)52,51,52
      51  STOP
          END
```

PROGRAM 2

```
      DIMENSION X(10),SWIZI(10),VARP(10),A(12),ID(20)
      IZIN=5
      IZOUT=6
C  IZIN=CARD READER.  IZOUT=PRINTER
      READ(IZIN,1)(ID(I),I=1,20)
    1 FORMAT(20A4)
      WRITE(IZOUT,2)(ID(I),I=1,20)
    2 FORMAT(1H1,20A4)
   52 READ(IZIN,32)J
   32 FORMAT(10X,I2)
      Z=0
      SWIZ=0
      VARPZ=0
      SWIJ=0
      DO 5 K=1,J
      SWIZI(K)=0
    5 VARP(K)=0
    3 READ(IZIN,4)P,(X(I),I=1,J)
    4 FORMAT(10X,F6.3,10F6.2)
      IF(P)34,37,34
   34 WIJ=1./P
      ZI=P
      DO 17 K=1,J
      SWIZI(K)=WIJ*X(K)+SWIZI(K)
   17 VARP(K)=WIJ*(X(K)**2)+VARP(K)
      SWIJ=WIJ+SWIJ
      Z=Z+1.
      VARPZ=WIJ*(ZI**2)+VARPZ
      GO TO 3
   37 WRITE(IZOUT,40)Z
   40 FORMAT(21HONUMBER OF SAMPLES = ,F7.0)
      SWIZ=Z/SWIJ
      VARPZ=(VARPZ-((SWIZ**2)*SWIJ))/((Z-1.)*SWIJ)
      WRITE(IZOUT,38)SWIZ
   38 FORMAT(46HOWEIGHTED AVERAGE FOR SAMPLING PROBABILITIES =,F10.4)
      WRITE(IZOUT,33)VARPZ
   33 FORMAT(38H VARIANCE FOR SAMPLING PROBABILITIES =,F12.4)
      DO 20 K=1,J
      SWIZI(K)=SWIZI(K)/SWIJ
      VARP(K)=(VARP(K)-((SWIZI(K)**2)*SWIJ))/((Z-1.)*SWIJ)
      WRITE(IZOUT,22)K,SWIZI(K)
   22 FORMAT(28HOWEIGHTED AVERAGE FOR DATUM I2,3H = F10.4)
   20 WRITE(IZOUT,30)K,VARP(K)
   30 FORMAT(41H WEIGHTED VARIANCE OF THE MEAN FOR DATUM I2,3H = F12.4)
      READ(IZIN,50)INT
   50 FORMAT(I6)
      IF(INT-999999)52,51,52
   51 STOP
      END
```

VARIABLE NAMES FOR PROGRAMS 1 AND 2

Variable	Meaning
A(L)	Days in year that have elapsed up to the beginning of month L.
ID(I)	Provision for an alphanumeric label of up to 80 characters.
J	Number of different observations or measurements made for each individual in the sample.
B	The first on-the-hour time that sampling can begin. This is coded from 01 to 24.
E	The last on-the-hour time that sampling can occur. This is also coded from 01 to 24.
Q and QW	Values coded as -1, 00, or +1 and 00 or +1, respectively, that permit computations to be directed to Scheme A, B, C, D, E, or F.
Z	A counter to record number of individuals in sample.
SWIZ	Summation of weighting factor times length of stay (in Program 1) or other sampling probability (Program 2). SWIZ also is used as this summation divided by the summation of the weighting factors.
VARPZ	Summation of weighting factors times squared lengths of stay (in Program 1) or times squared sampling probabilities (Program 2). VARPZ is also used as the variance for lengths of stay (Program 1) and as variance for sampling probabilities (Program 2).
SWIJ	Summation of the weighting factors.
SWIZI(K)	Summation of weighting factors times values of a variable. SWIZI(K) is also used as this summation divided by SWIJ.
VARP(K)	Summation of weighting factors times squared values of a variable. VARP(K) is also used as variance for such an observation or measurement.
F1	Month of arrival.
F2	Day of month of arrival.
F3	Hour of day of arrival.
AL1	Month of departure.
AL2	Day of month of departure.
AL3	Hour of day of departure.
X(I)	Value of variable I as observed for each individual in the sample. (I goes from 1 to j.)
AF3	Number of hours of possible exposure to sampling on day of arrival.
AL3A	Number of hours of possible exposure to sampling on day of departure.
T	Number of days on which present.
WIJ	The weighting factor. This equals the inverse of the sampling probability.
ZI	The probability of being included in the sample.
P	The probability of being included in the sample.
INT	A variable used at end of data to stop program.

BIBLIOGRAPHY

1. Deming, W. Edwards.
   1944. Statistical Adjustment of Data, pp. 18-20. New York: John Wiley & Sons.
2. Hewston, John G.
   1965; 1966. Unpublished reports on file at Utah Cooperative Fishery Unit, Utah State Univ., Logan, Utah.
3. Lucas, Robert C.
   1963. Bias in estimating recreationists' length of stay from sample interviews. J. Forest. 61:912-914.
4. ________, and Dennis L. Schweitzer.
   1965. Outdoor recreation surveys: length-of-stay bias and its correction by computer. U.S. Forest Serv. Res. Note LS-68, 2 pp.

Research Note

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

U.S.D.A. Forest Service
Research Note INT-80 1968

ROOTING OF NEEDLE FASCICLES FROM WESTERN WHITE PINE SEEDLINGS

by

Raymond J. Hoff and Geral I. McDonald[1]

ABSTRACT

In one test, 45 out of 318 (14 percent) needle fascicles from 2-year-old seedlings of Pinus monticola Dougl. were rooted. Eight of the needle fascicles produced shoot growth. In another test, 392 out of 742 (53 percent) needle fascicles were rooted, but none of these produced shoot growth.

The production of genetically uniform, clonal lines of host plants is extremely important to fundamental investigation of plant disease resistance. Such lines supply the investigator with a powerful tool for assessing resistance reactions in the host and virulence characteristics of any biotypes of the pathogen. Knowledge of both is needed for increasing efficiency, economy, and security of resistance breeding.

In studying the western white pine:blister rust system (Pinus monticola Dougl: Cronartium ribicola J.C. Fisch.ex Rabenh.), we can produce clonal lines of the alternate host plant (Ribes spp.) with relative ease from rooted stem cuttings. However, rooting of the pine host has proven difficult. Deuber (1942) didn't obtain any rooted cuttings out of 120 taken from a 45-year-old tree, but he obtained 11 rooted cuttings from 196 taken from a 56-year-old tree. Furthermore, although production of grafted, clonal lines of western white pine is attainable (Bingham, Squillace, and Duffield 1953); Hanover 1966), the grafted plants are far from ideal for the study of blister rust resistance. First, they are relatively expensive to produce and maintain (Bingham 1966). Second, they recover quite slowly from the setback of graftage, and thus, for a year or two may remain erratic in respect to their susceptibility to the rust (Patton 1961; Bingham 1966). Third, where more than a few ramets are required, the ortet must be relatively large (thus old) and ease of inoculation decreases directly with age of white pine plants (Patton 1961). Lastly, any variation introduced by genetically heterogeneous rootstocks cannot be controlled.

---

[1]Research Geneticists, stationed in Moscow, Idaho 83843, at Forestry Sciences Laboratory, maintained in cooperation with University of Idaho.

For these reasons we are interested in rooting needle fascicles of young western white pines. If fascicles can be rooted with even a moderate degree of success, clones with relatively large numbers of members may be obtained even from 2-year-old plants. For certain work, in fact, rooted fascicles that fail to produce shoots but remain alive more than a year or so may suffice.

Various workers have successfully rooted fascicles of young "hard" pines (Jeckalejs 1956; Isikawa and Kusaka 1959; Mergen and Simpson 1964; Reines and Bamping 1964; Rudolph and Nienstaedt 1964; and Kummerow 1966). Thimann and Delisle (1942) have successfully rooted needle fascicles of P. strobus, a "soft" pine, and workers at the Pacific Southwest Forest and Range Experiment Station have successfully rooted other species of "soft" pines including western white pine.[2] This paper reports moderate success attained in rooting needle fascicles of young western white pine.

During the first week of February two tests were installed. For one, needle fascicles with 2- to 3-mm.-long buds were removed from the apical leader of 2-year-old greenhouse-grown, dormant western white pine seedlings. The fascicles were treated with Rootone,[3] which contains 0.067% naphthylacetamide, 0.033% 2-methyl-1-naphthylacetic acid, 0.013% 2-methyl-1-naphthylacetamide, and 0.05% indole-3-butyric acid. These then were planted in a washed-sand culture, and placed in a greenhouse with a 16-hour photoperiod at an air temperature of about 72° F. In the second test, fascicles were taken from nursery-grown 2-year-old seedlings. Very few of these fascicles contained a fascicular bud. They were planted in a soil mixture of equal parts of sand and peat moss culture but were not given a hormone treatment. They were then placed in the same environmental conditions as in the first test. Differences between the two tests arose because the rooting of fascicles was not the objective of the second test.

During the first week of July, a tally was made of the total rooted fascicles and shoot growth in the first test and of rooted fascicles only in the second test. The total rooted was 45 out of 318 (14 percent) for the first test (table 1) and 392 out of 742 (53 percent) for the second test (table 2). Eight of the rooted fascicles in test 1 produced shoot growth (table 1, fig. 1). Shoot growth was not noted for the second test due to the absence of budded fascicles.

Tables 1 and 2 also show that rooting ability may be closely controlled by genotype. This is especially evident when tree 224 in table 1 and trees 255 and 382 in table 2 are compared with tree 272 in table 1 and trees 60 and 235 in table 2.

Having attained this moderate success, we will now test different treatments and culture methods, hoping for an increase in the rooting and shoot growth percentages. The differences found in the two tests described above indicate a real potential for increasing rooting, if not for increasing shoot growth. Disbudding plants to encourage the continued development of fascicular buds (Kummerow 1966; Ginzburg and Reinhold 1967) holds much promise for increasing the proportion of rooted fascicles with shoot growth.

---

[2]Personal communication from Dr. Stanley L. Krugman.

[3]Use of trade names herein is for identification only and does not necessarily imply endorsement by the U.S.D.A. Forest Service.

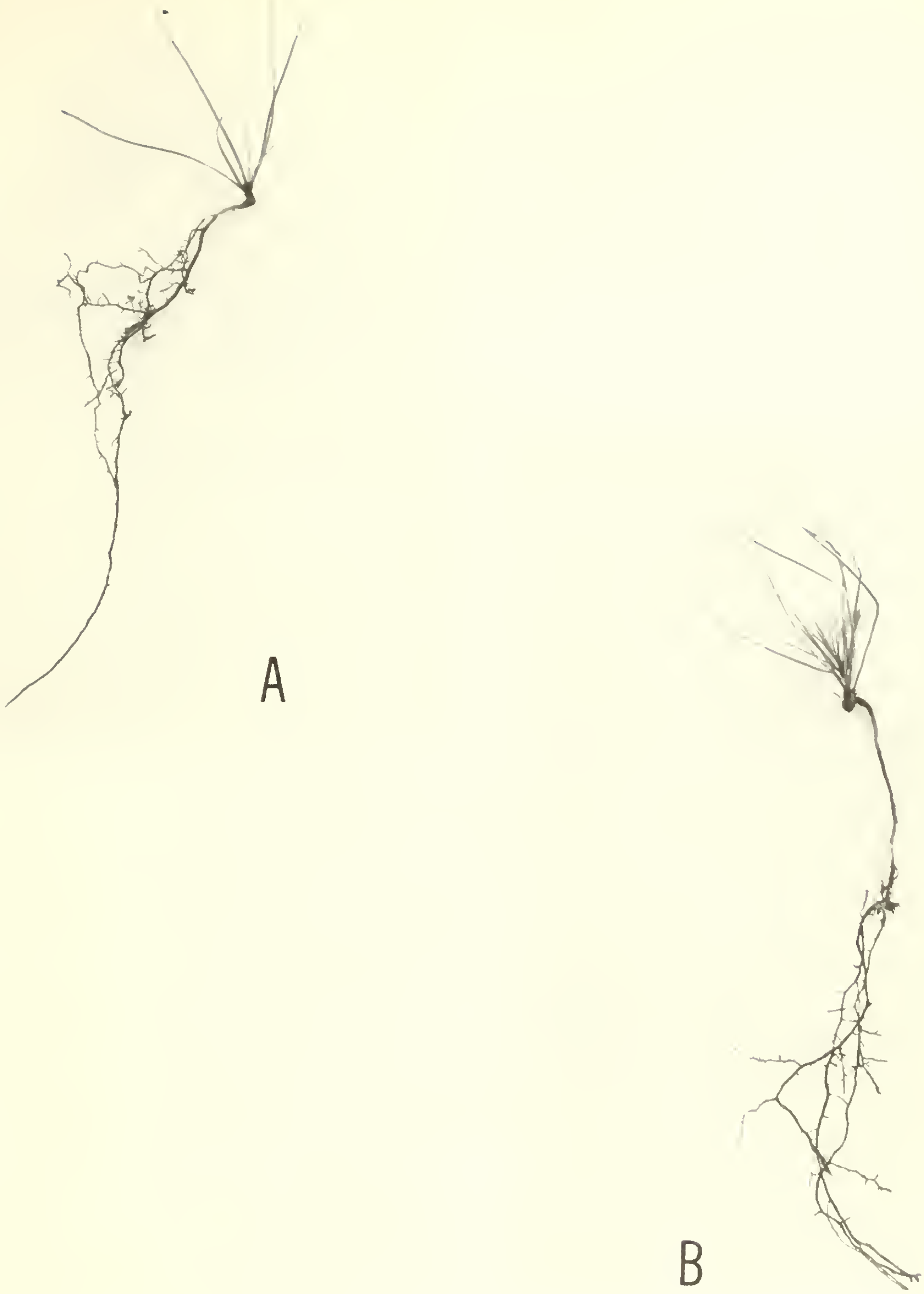


Figure 1.--A rooted needle fascicle of western white pine: *A*, without shoot growth; *B*, with shoot growth.

Table 2.--Number of fascicles rooted following planting in a soil mixture of sand and peat moss culture of needle fascicles from nursery-grown western white pine seedlings

Female tree no.	Male tree no. 17 Fascicles Rooted	17 Planted	19 Fascicles Rooted	19 Planted	22 Fascicles Rooted	22 Planted	58 Fascicles Rooted	58 Planted	Totals Fascicles Rooted	Totals Planted
33	--	--	1	1	4	10	0	1	5(42)[1]	12
60	7	12	5	5	5	10	6	11	23(61)	38
67	--	--	8	9	6	9	2	5	16(70)	23
95	1	1	--	--	1	2	5	12	7(47)	15
99	2	10	5	12	4	6	3	5	14(42)	33
112	--	--	3	3	3	7	2	6	8(50)	16
115	0	9	6	11	3	3	2	5	11(39)	28
121	2	7	3	8	7	12	7	11	19(50)	38
138	1	4	2	3	7	9	4	6	14(64)	22
177	3	12	9	11	1	6	3	6	16(46)	35
179	5	8	0	4	7	10	5	12	17(50)	34
184	10	10	5	7	5	9	0	7	20(61)	33
211	1	9	4	7	8	9	6	7	19(59)	32
227	4	8	3	5	1	2	0	3	8(44)	18
230	3	10	3	8	8	10	4	8	18(50)	36
232	4	4	10	12	1	2	5	7	20(80)	25
235	2	4	11	11	1	1	9	12	23(82)	28
255	4	9	3	12	6	7	0	3	13(42)	31
261	4	7	7	11	1	11	2	4	14(42)	33
262	2	4	5	11	4	11	5	9	16(46)	35
265	9	11	5	8	1	1	3	3	18(78)	23
269	1	1	3	9	3	3	5	6	12(63)	19
274	--	--	2	9	--	--	1	5	3(21)	14
382	0	1	1	3	1	11	1	7	3(14)	22
383	2	3	6	10	4	5	3	11	15(52)	29
384	--	--	2	2	5	9	5	5	12(75)	16
252	5	6	--	--	1	4	5	12	11(50)	22
263	7	9	7	11	2	4	--	--	16(67)	24
57	1	8	--	--	--	--	--	--	1(13)	8
Total	80(45)	167	119(53)	203	100(55)	183	93(49)	189	392(53)	742

[1] Numerals in parentheses are percentile values of fascicles rooted to fascicles planted.

Table 1.--Number of fascicles rooted and shoots produced following planting in washed-sand culture of hormone-treated needle fascicles from greenhouse-grown western white pine seedlings

Female tree no.	Male tree no. 17 Fasc. rooted	17 Shoots prod.	17 Fasc. planted	19 Fasc. rooted	19 Shoots prod.	19 Fasc. planted	22 Fasc. rooted	22 Shoots prod.	22 Fasc. planted	58 Fasc. rooted	58 Shoots prod.	58 Fasc. planted	Total Fasc. rooted[1]	Total Shoots prod.[2]	Total Fasc. planted
277	2	0	12	1	0	12	1	0	12	1	0	12	5(10)	0	48
208	1	0	12	1	1	12	2	1	12	2	0	12	6(13)	2(4)	48
272	1	0	6	5	1	9	3	0	8	1	0	7	10(33)	1(3)	30
197	0	0	12	3	0	12	4	2	12	0	0	12	7(15)	2(4)	48
15	2	0	12	0	0	12	3	1	12	3	0	12	8(17)	1(2)	48
20	1	1	12	1	1	12	2	0	12	5	0	12	9(19)	2(4)	48
224	0	0	12	0	0	12	0	0	12	0	0	12	0	0	48
Total	7(9)[1]	1(1)[2]	78	11(14)[1]	3(4)[2]	81	15(19)[1]	4(5)[2]	80	12(15)[1]	0	79	45(14)	8(3)	318

[1]Numbers in parentheses represent percentile values of fascicles rooted to fascicles planted.
[2]Numbers in parentheses represent percentile values of shoots produced to fascicles planted.

REFERENCES

Bingham, R. T.
1966. Breeding blister rust resistant western white pine. III. Comparative performance of clonal and seedling lines from rust-free selections. Silv. Genet. 15: 141-192.

Bingham, R. T., A. E. Squillace, and J. W. Duffield.
1953. Breeding blister rust resistant western white pine. J. Forest. 51: 163-168

Deuber, C. G.
1942. The vegetative propagation of eastern white pine and other five-needled pines. J. Arn. Arb. 23: 199-215.

Ginzburg, M. W., and L. Reinhold.
1967. The development of techniques for the vegetative propagation of pine trees by means of needle fascicles. Hebrew Univ. Jerusalem Rep. for U.S. Dep. Agr., Forest. Serv. P.L. 480. Proj. A10-FS-8, 36 pp.

Hanover, J. W.
1966. Genetics of terpenes. I. Gene control of monoterpene levels in *Pinus monticola* Dougl. Heredity 21: 73-84.

Isikawa, H., and M. Kusaka.
1959. The vegetative propagation of cutting of Pinus species. 1. Vegetative propagation of Japanese black pine using leaf-bundles. Bull. Forest. Exp. Sta. Meguro, Tokyo, Japan 116: 59-64.

Jeckalejs, H. J.
1956. The vegetative propagation of leaf-bundle cuttings of red pine, *Pinus resinosa*. Forest. Chron. 32: 89-93.

Kummerow, J.
1966. Vegetative propagation of *Pinus rigida* by means of needle fascicles. Forest Sci. 12: 391-398.

Mergen, F., and B. A. Simpson.
1964. Asexual propagation of *Pinus* by rooting needle fascicles. Silv. Genet. 13: 125-164.

Patton, R. F.
1961. The effect of age upon susceptibility of eastern white pine to infection by *Cronartium ribicola*. Phytopathology 51: 429-434.

Reines, M., and J. H. Bamping.
1964. Rooting of needle bundles. J. Forest. 62: 181-182.

Rudolph, T. D., and H. Nienstaedt.
1964. Rooting, shoot development and flowering of jack pine needle fascicles. Silv. Genet. 13: 118-124.

Thimann, K. V., and A. L. Delisle.
1942. Notes on the rooting of some conifers from cuttings. J. Arn. Arb. 23: 103-109.

Research Note

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

U.S.D.A. Forest Service
Research Note INT-81 1968

WESTERN WHITE PINE CONES POLLINATED WITH 1- TO 3-YEAR-OLD POLLENS GIVE GOOD SEED YIELDS

R. T. Bingham and K. C. Wise[1]

ABSTRACT

Filled seed yields of Pinus monticola cones from 55 controlled crosses made with 1- to 5-year-old, deep-freeze-stored pollens were compared with yields from other fresh-pollen crosses made on the same trees in the same pollination seasons. Observations covered four pollination seasons, and on the average involved about 11 trees, and 14 stored-pollen and 25 fresh-pollen crosses thereon, per season. One- to 3-year-old pollens gave 52 to 110 percent of the yield observed for fresh pollens, and there was some evidence that 4- and 5-year-old pollens might also be satisfactory for routine use.

In the course of 18 years' work toward breeding varieties of western white pine resistant to attack by the blister rust fungus (Pinus monticola Dougl. resistant to attack by Cronartium ribicola J. C. Fisch. ex Rabenh.), we have attempted several thousand controlled intraspecies crosses. Whenever possible, freshly extracted pollens have been obtained for this work. Occasionally, however, we have encountered trees lacking sufficient pollen during the season they were scheduled for use as pollen parents. More frequently--even with greenhouse "forcing" of pollen-bearing branches--we have been unable to secure pollens from phenologically late trees (usually high-elevation or other cold-site trees) in time for use. The inaccessibility of other trees in years of heavy snowpack has prevented pollen collection.

[1]Research Geneticist and Forestry Research Technician, respectively, stationed in Moscow, Idaho 83843, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

To supply this occasional need, as early as 1951 we began using pollens that were stored in a household refrigerator (at 35° to 40° F.). These pollens were unsatisfactory. Although germination counts often showed 80 to 90 percent viability, sound seed set was very low. In this respect, Callaham and Steinhoff[2] have shown that western white pine pollens stored at about 41° F. were incapable of producing sound seed after 2 years of storage.

After 1960 we began to store pollens in a household "deep-freeze" unit, at 0° to 5° F., and thereafter used 1- to 5-year-old stored pollens from this unit in making some 60 intraspecies crosses. In 55 of these crosses--involving 28 trees and four pollination seasons--one or more crosses utilizing fresh pollens were made simultaneously. The 28 different trees were in 11 stands located 2 to 150 miles apart and ranging between 2,950 and 5,100 feet in elevation.

Thus, although truly paired samples (using both stored and fresh pollen of the same pollen parent, on the same mother trees in the same year) or samples using the same stored pollen in successive years were not available, results from these pollinations in a number of trees and seasons are of value for determining general utility of deep-freeze-stored pollens. Summarized results are given in table 1. Determination of statistical significance of differences has not been attempted.

Wide differences in filled-seed yield were associated with pollination years. The 1964 pollinations gave relatively low seed yields, and 1966 pollinations relatively high ones, in both stored- and fresh-pollen crosses.

Within 2 pollination years, where tree, cross, and cone basis was adequate, filled-seed yield in crosses made with 1- to 3-year-old pollens ran 36 to 95 percent of that of fresh-pollen crosses; and on the average, 1- and 2-year-old pollen crosses produced 88 to 110 percent as many sound seed as corresponding fresh-pollen crosses. In a single relatively poor seed year (1964), however, 3-year-old pollens produced only about 50 percent as many filled seed as fresh pollens. Results, in general, agree with those reported for *P. monticola* by Callaham and Steinhoff (see footnote 2); however, these authors showed that 5-year-old pollens produced seed yields ranging from 25 to 90 percent of those obtained with fresh pollens.

From this we conclude that rather than delay scheduled pollinations, particularly "windup" work in remote areas, it will be safe and greatly advantageous to substitute deep-freeze-stored pollens, up to 3 and possibly 5 or more years old, for fresh pollens.

---

[2] Callaham, R. Z., and R. J. Steinhoff. Pine pollens frozen five years produce seed. Pp. 94-101, in Proc. 2nd Forest Genetics Workshop, 1965. U.S. Dep. Agr., Forest Serv. Res. Pap. NC-6, 110 pp. 1966.

Table 1.--Seed yield with stored and fresh pollens

Pollination year	Number of trees pollinated	Stored pollen: Pollen age	Stored pollen: Crosses made[1]	Stored pollen: Cones extracted[2]	Stored pollen: Sound seed per cone[3]	Fresh pollen: Crosses made[1]	Fresh pollen: Cones extracted[2]	Fresh pollen: Sound seed per cone[3]	Seed yield with stored pollen (% of fresh pollen seed yield)
		Years							
1962	7	1	7	42.5	42.2	9	38	38.5	109.6
1964	5	1	6	67	11.1	7	89	30.9	35.9
	1	2	2	40	8.4	1	14	1.2	[4]700.0
	12	3	14	158	44.2	16	247	85.7	51.6
	2	4	2	10	7.0	2	13	42.5	[4]16.4
1965	4	1	8	44	70.1	16	127	85.9	81.6
	6	2	6	33	71.1	23	193	75.0	94.8
1966	6	1	8	35	111.7	26	182.5	111.2	100.4
	1	2	1	7	138.0	2	9	122.5	[4]112.6
	1	5	1	4	105.0	5	27	87.0	[4]120.7
All years	22	1	29	188.5	58.8	58	436.5	66.6	88.3
	8	2	9	80	72.5	26	216	66.2	109.5
	12	3	14	158	44.2	16	247	85.7	51.6

[1]Crosses were made using 28 different trees, some crossed in more than 1 pollination year.

[2]Total for all crosses; insect-infested portions of cones not included.

[3]Average weighted by number of cones per cross to neutralize effect of erratic average seed yields in crosses that produced very few cones.

[4]Tree, cross, and cone basis inadequate for meaningful comparison.

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

U.S.D.A. Forest Service
Research Note INT-82

1968

DEVELOPMENT OF A TORSIONAL DYNAMOMETER

Ron E. Schmidt and Richard Herbert[1]

ABSTRACT

This report presents the design and evaluation of a photoelectric device used for measuring the input power requirements of rotating machinery. Mechanical and electronic design considerations are presented, along with an operational evaluation of the device.

A multirange torquemeter utilizing interchangeable load shafts provides effective instrumentation of pump input power requirements for hydraulic research conducted by Intermountain Forest and Range Experiment Station in cooperation with the Department of Civil Engineering and Engineering Mechanics of Montana State University. The design is readily adaptable to other applications requiring measurement of power requirements of rotating machinery. A photoelectric principle used in the design provides:

1. Signal generation and transmission without physical contact with the shaft (i.e., no slip rings);
2. Rpm counting capabilities inherent in the design; and
3. Load range flexibility with interchangeable shafts.

Basic Design Concept

The basic design, shown in figure 1, incorporates a slender shaft mounted in its own bearings. Two serrated disks are mounted on the shaft. These disks interrupt the light beam passing between each of two sets of lights and photodiodes, thus producing two interrupted light patterns.

Electronic circuitry converts each light pattern into a d.c. voltage pulse. Angular displacement of one disk relative to the other produces a phase shift in the pulse patterns. Electronic sensing of the shift produces a constant d.c. output proportional to the phase shift; thus the output is also proportional to shaft torque. Measurement of pulse frequency from one disk is a direct indication of shaft rotational speed.

---

[1]Respectively, Research Hydraulic Engineer, stationed in Bozeman, Montana 59715, at Forestry Sciences Laboratory, maintained in cooperation with Montana State University; and Graduate Assistant in Electronics Research, Montana State University.

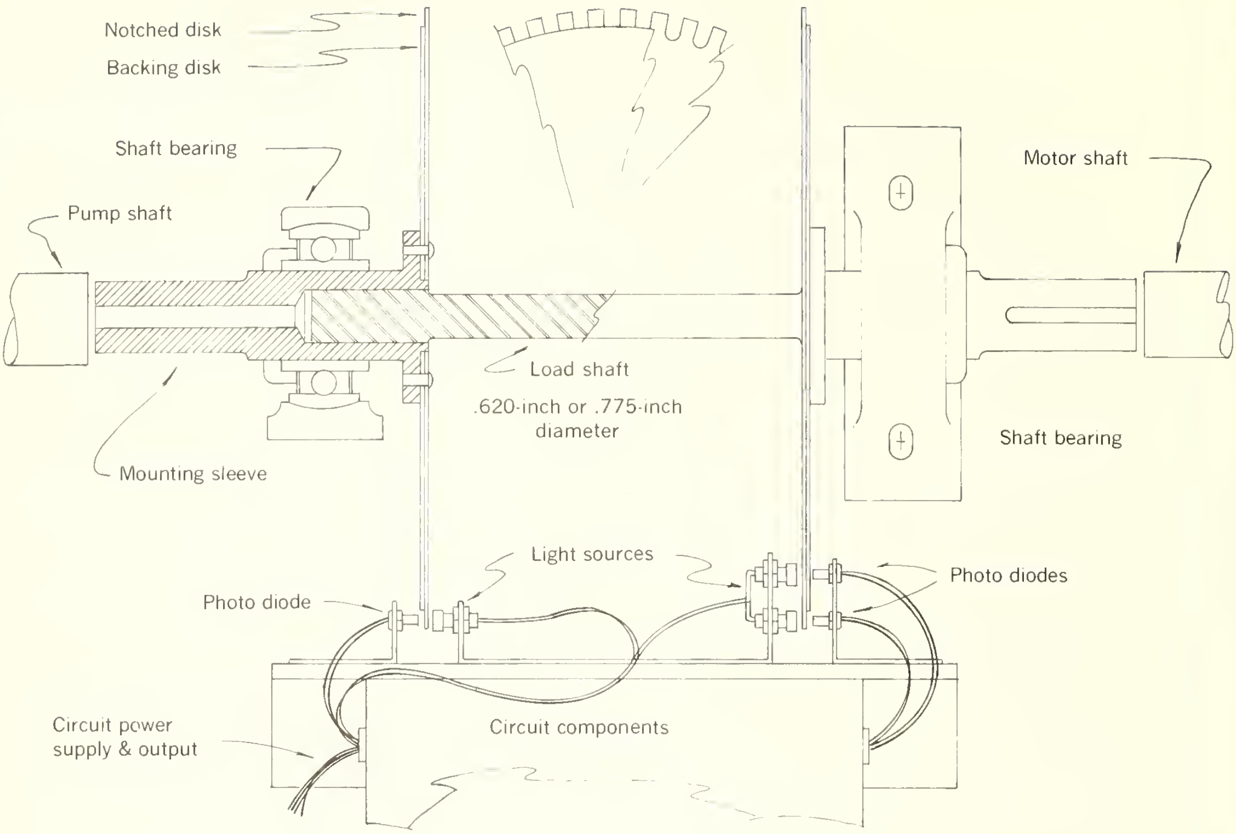


Figure 1.--Torque shaft assembly.

Mechanical Design

The design required a shaft material with sufficient strength to transmit the desired load without permanent deformation, yet sufficiently elastic to enable resolution of small load changes. Aluminum alloy 2024 T4 was selected, although other available metals and metal alloys would have met these requirements. The physical properties of 2024 T4 are as follows:

Yield strength	47,000 p.s.i.
Shear strength	41,000 p.s.i.
Fatigue limit	20,000 p.s.i.
Modulus of elasticity	10.6×10^6 p.s.i.

Load shaft diameter for 6-inch-long shaft was determined using these equations:

$$J = 57.3TL/E_s \phi \qquad (1)$$

$$d = \sqrt[4]{32J/\pi} \qquad (2)$$

T = load torque in inch-pounds
L = shaft length in inches
E_s = modulus of elasticity of the material
ϕ = angular deformation in degrees
J = polar moment of inertia
d = shaft diameter in inches

Setting 2.5 degrees as the maximum angular deformation, shafts of 0.620-inch and 0.775-inch diameter were selected for load capacities of 500 and 1,000 inch-pounds.

The shear stress on these shafts at design load was determined by equation (3) to be below 11,000 p.s.i.

$$T = Tc/J = 16T/\ d^3 \qquad (3)$$

T = shear stress
c = distance to outer fiber of the shaft = d/2

Sixty evenly spaced notches were cut into each of the disks. The desired notch size and spacing were obtained by milling the notches 0.250 inch deep in the edge of the 10-inch-diameter disks. Two backup disks (9.550 inches in diameter) were riveted to each 10-inch disk to provide the desired 3-degree square-edge opening and to add stiffness to the disk assembly.

Steel shaft adapters, which were machined to provide bearing support for the load shaft, permit quick exchange or replacement of the shaft and also serve as the mounting for the serrated disks.

The entire shaft assembly rides in pillow bearings firmly mounted to a base assembly. This base assembly, which mounts to the motor and pump base, provides vertical and horizontal adjustment to enable exact alinement of the dynamometer. The stationary lights, photodiodes, and circuitry are mounted on the base assembly.

Electronic Design

The electronic design of the torquemeter can best be followed by referring to figure 2. As the serrated disks interrupt the light to each photodiode, the resistance of these diodes increases. The voltage drop across this changing resistance is amplified and fed into a Schmitt trigger. If the light is shining on the photodiode, the output of the Schmitt trigger will be -8.9 volts. If the light is blocked, the voltage will change to -1.7 volts. As the disks rotate, the output of the Schmitt trigger circuits will be a series of pulses as shown in the oscillograph photograph (fig. 3). Electronic differentiating and clipping the pulses result in impulses, one each time the light is blocked from a photodiode. Similar circuitry is used for each light-photodiode combination to this point.

In operation, as one disk is displaced relative to the other, the impulses created by each circuit are displaced in time. This set of impulses is used to control a bistable multivibrator. The first impulse switches the circuit to a negative voltage level; the lagging impulse returns the multivibrator to a voltage near zero. The result of this switching is a series of pulses; the width of these pulses is dependent on the angular relationship of the two disks (see figs. 4A and 4B). The height of these pulses is constant; therefore, the area under the pulse per unit time is a measure of the torsional load on the shaft. The pulses are integrated by a resistance-capacitance network giving a d.c. voltage output. This voltage is amplified by an operational amplifier to the desired full load level of 1,000 millivolts.

The disks are adjusted on the shaft to give a narrow pulse width from the multivibrator at no-load conditions (figs. 2 and 4). This prevents instability that would result from two pulses arriving at the bistable multivibrator simultaneously. The low output voltage that occurs from this adjustment can be canceled out by a variable resistor in the output circuitry to give a zero output at no-load conditions.

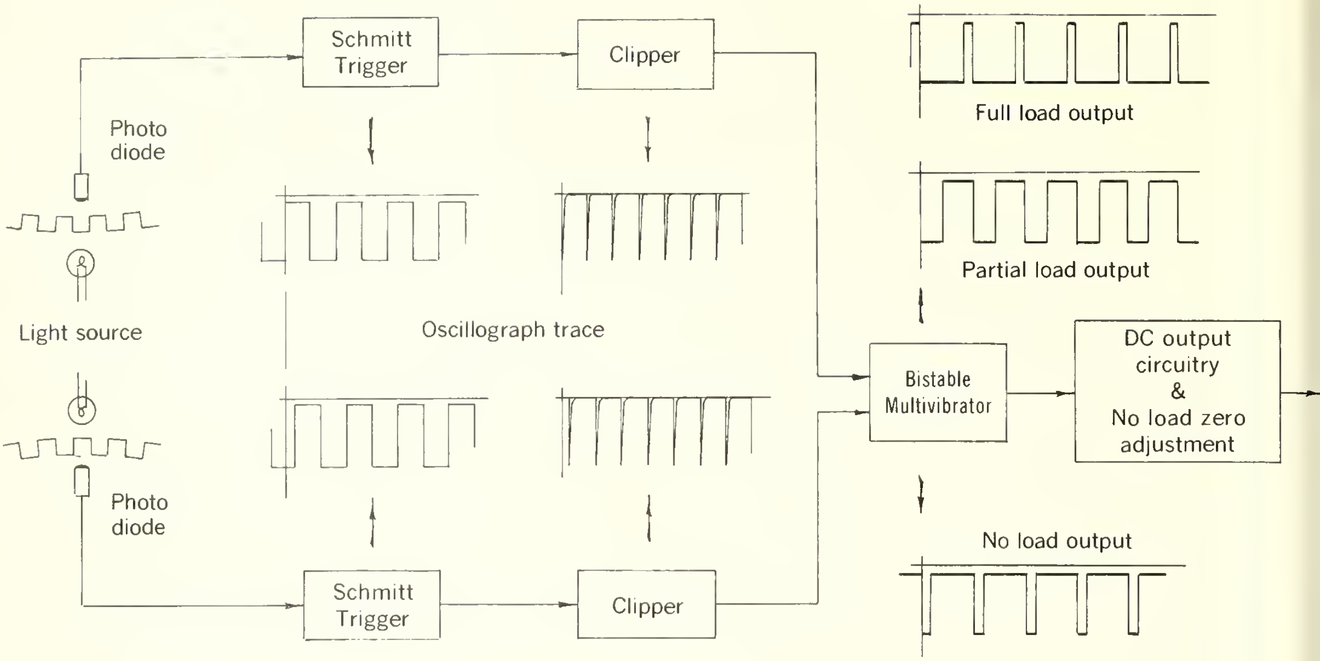


Figure 2.--Schematic of circuit operation.

The rotational speed of the shaft is counted by an electronic frequency counter that simply counts the pulse frequency of one disk. Since the disk has 60 teeth, the pulse count in cycles per second is exactly the same as the speed in revolutions per minute.

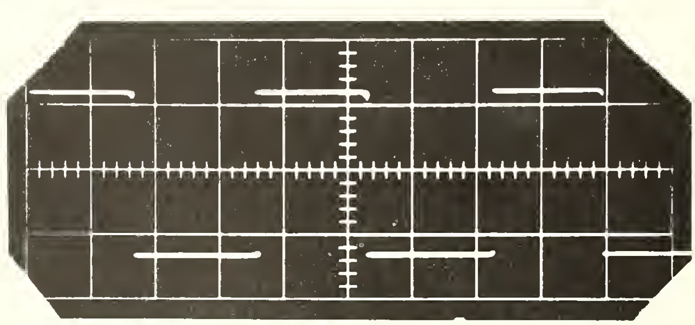
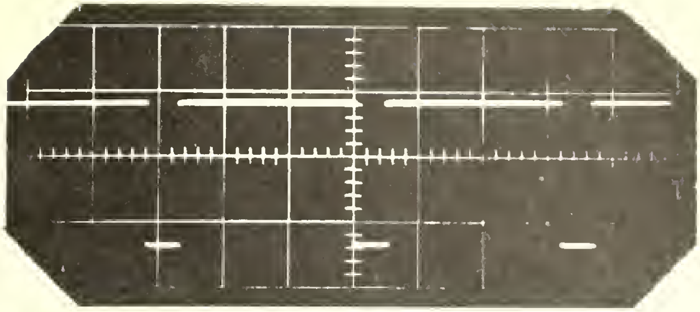


Figure 3.--Schmitt trigger output--each disk.

A



B

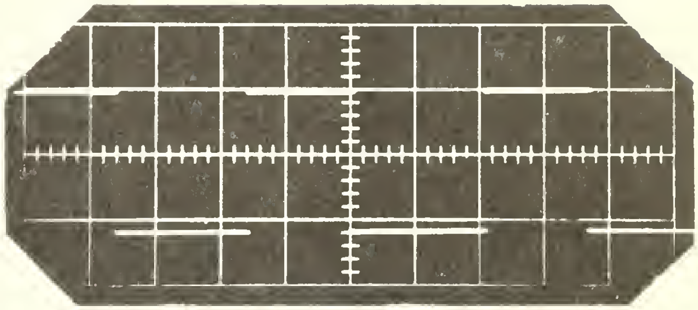


Figure 4.--A, No load multivibrator output; B, partial load multivibrator output.

Calibration

Since the basic principle of operation of the unit is the electronic sensing of the time lag between pulses generated by shaft distortion during rotation, the unit could not be statically calibrated. Thus, the unit was calibrated using a 15-hp d.c. motor as the driving unit and a d.c. dynamometer as the calibrating unit. A diesel-driven d.c. generator was used to supply power to the motor. Motor speed was controlled by the voltage output of the diesel generator and by rheostat control of the motor field current. The electric dynamometer was supplied with constant 220-volt d.c. power. A digital voltmeter and a digital impulse counter were used as readout equipment. The layout of the calibration apparatus is shown in figure 5.

Accurate balance of the dynamometer was checked at all desired speeds before calibration was started. Calibration data were obtained for nominal shaft speeds of 800, 1,000, 1,200, and 1,400 r.p.m. An initial no-load reading was obtained when the unit was operating at the desired speed while disconnected from the load. The unit was then connected to the dynamometer. Weights were placed on the dynamometer balance arm; calibration was achieved by adjusting the field current of the dynamometer so as to cancel the external load. As each increment of applied load was balanced, the load, shaft speed, and voltage output were recorded. At the conclusion of each run, the no-load reading was again determined.

During the first calibration run on the small shaft, the shaft was accidentally overloaded. This unknown overload permanently twisted the shaft approximately 40 degrees before a circuit breaker tripped and relieved the load. As no other damage was apparent, the disks were repositioned to give the desired no-load output, and the calibration procedure was carried out.

Figure 6 presents a typical graph of shaft torque versus voltage output for the 0.650-inch-diameter shaft.

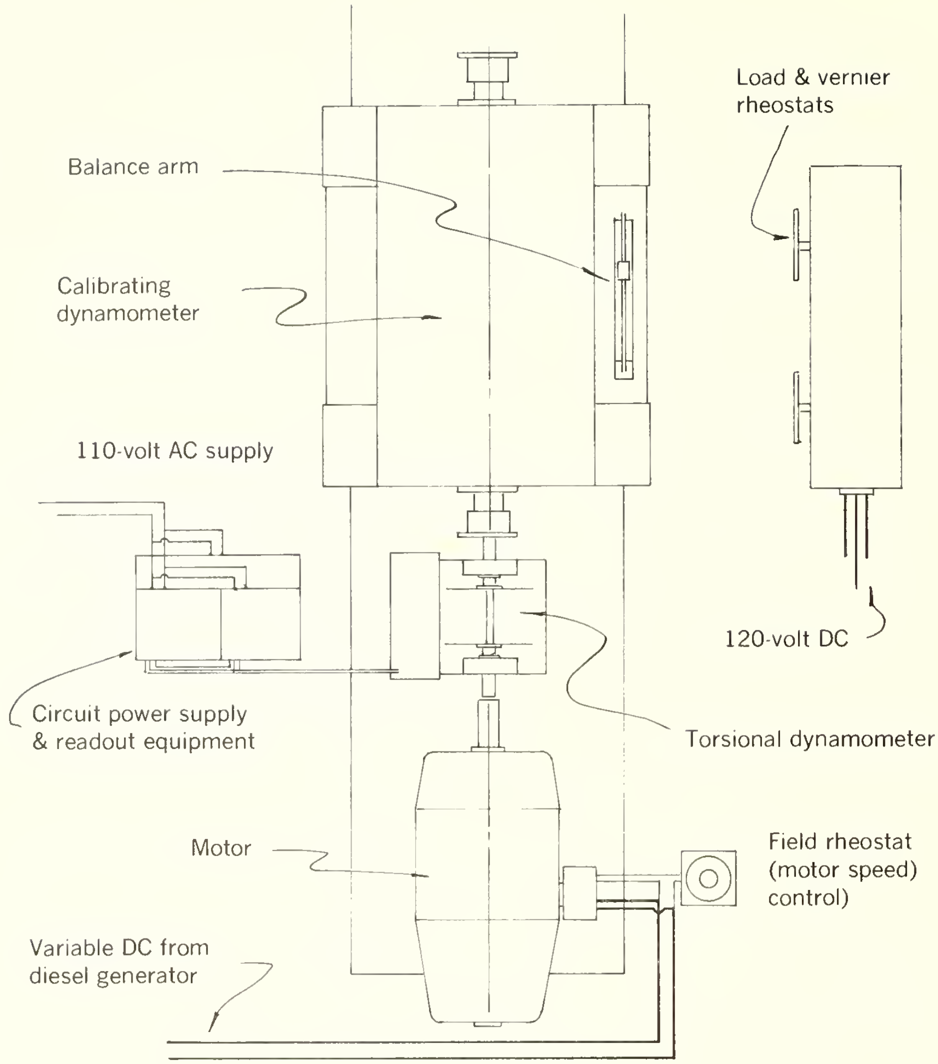


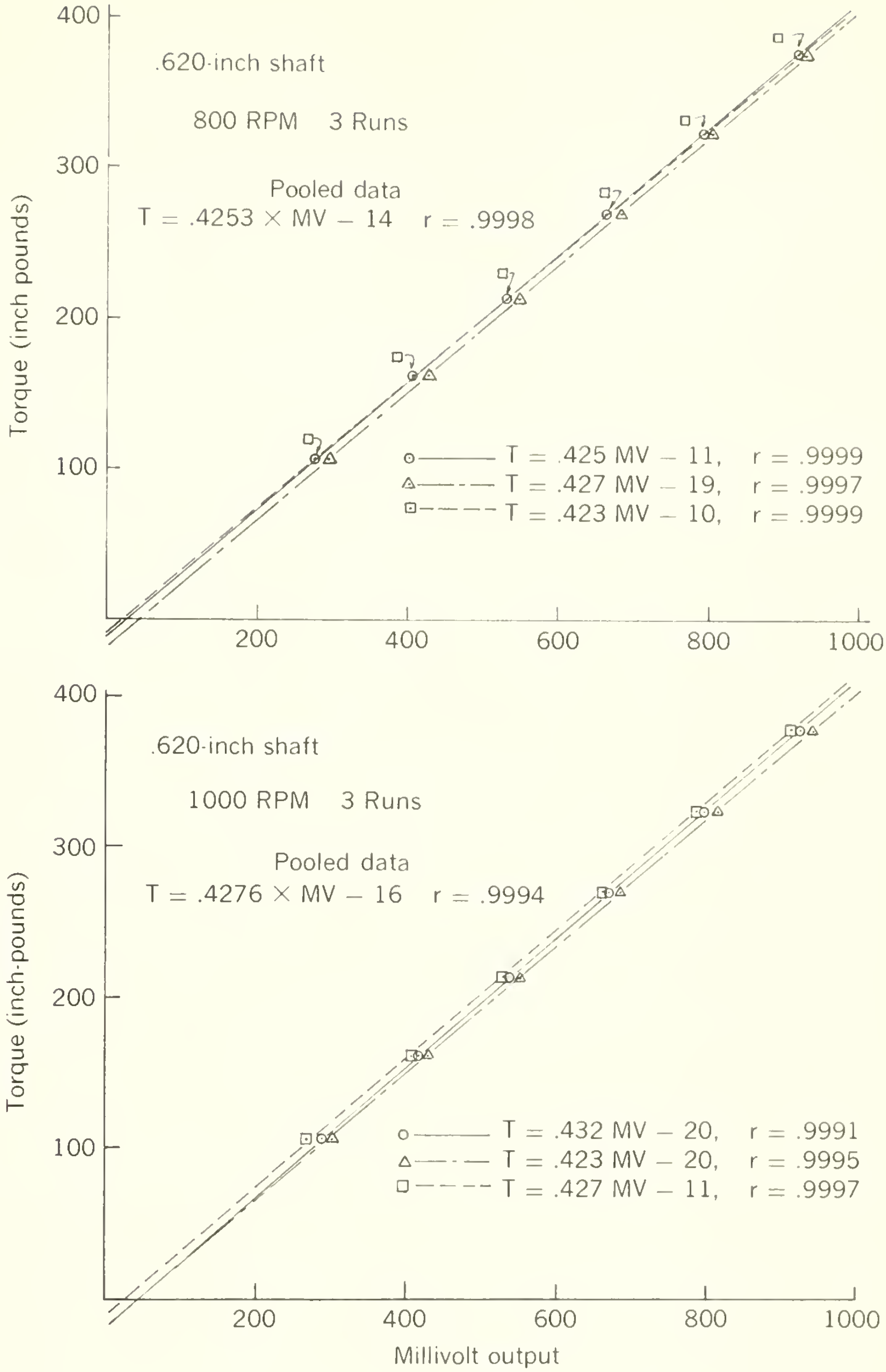
Figure 5.--Calibration equipment.

The 0.775-inch shaft was calibrated in the same manner. Care was taken to ensure that this shaft was not overloaded. Figure 7 presents typical results of these calibration runs.

In view of the excellent results obtained for the small shaft, the results obtained for the large shaft were considered unsuitable because of the excessive spread of calibration points. The only differences between the shafts were in size and state of material deformation.

A change in shaft size should affect only the total load capacity and not the repeatability of the stress-strain relationships. The state of material deformation could affect the stress-strain characteristics.

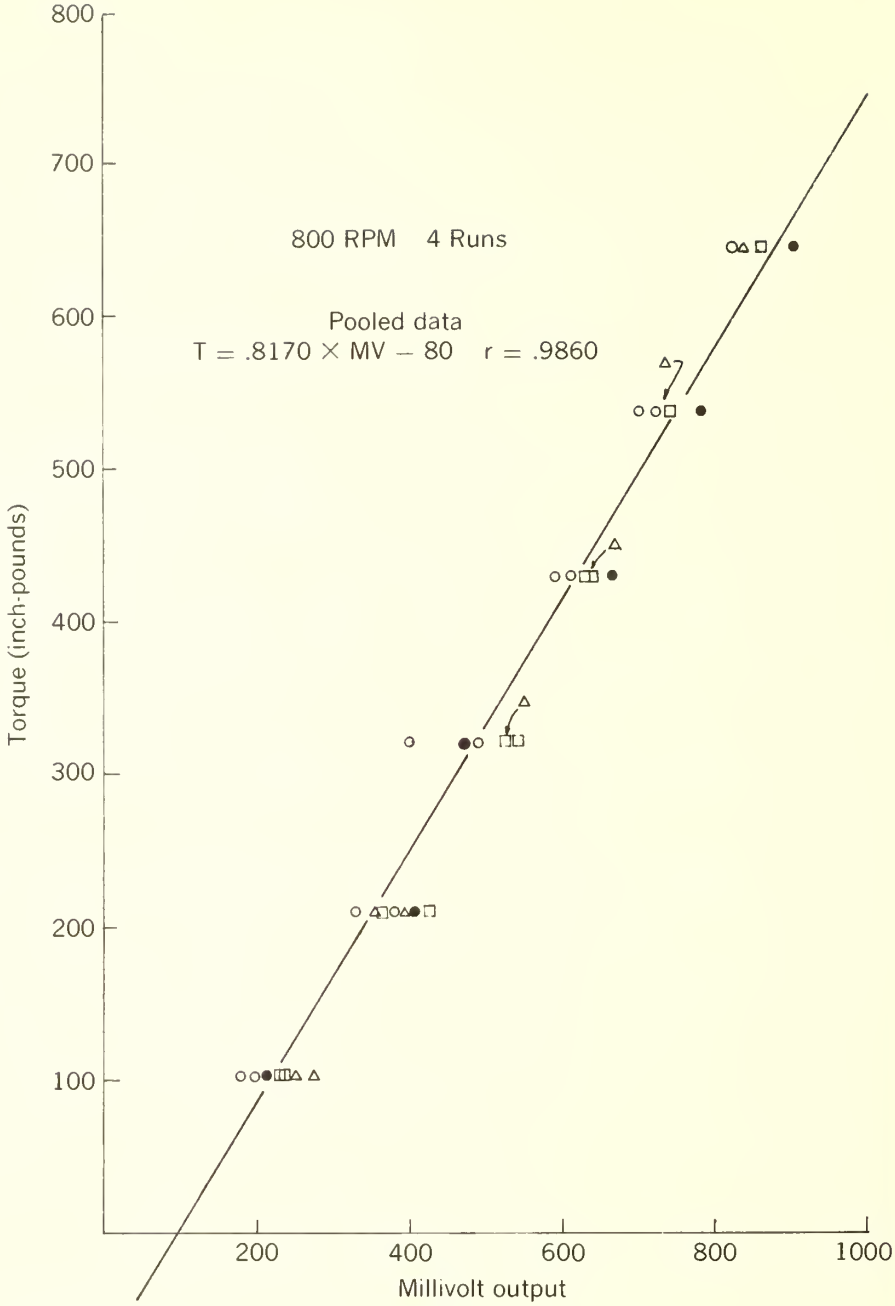
Figure 6.--Dynamometer output vs. torque.



Most aluminum alloys do not have a clearly defined elastic limit, and it is possible that stresses caused by starting torque or dynamometer loading may have exceeded the elastic limit even though the calculated stress was below 11,000 pounds per square inch.

Any permanent deformation would cause an increase in the voltage output of the photodiode circuitry. Any later relaxation of the shaft at lower loads would cause a decrease in voltage output.

Figure 7.--Dynamometer output vs. torque.



The unintentional deformation of the first shaft apparently stress-hardened the material and raised the elastic limit to a level high enough to preclude any further deformation at the starting speeds under design loads. This idealized condition is shown graphically in figure 8.

Improvement of the repeatability of the stress-strain characteristics at or near the elastic limit could be achieved by overloading the material. Therefore, we intentionally deformed the large shaft by mounting it between lathe centers and manually turning the headstock until the total deformation was approximately 40 to 45 degrees. The shaft was then recalibrated. Figure 9 presents the results of this calibration; a reduction in the spread of data is clearly evident.

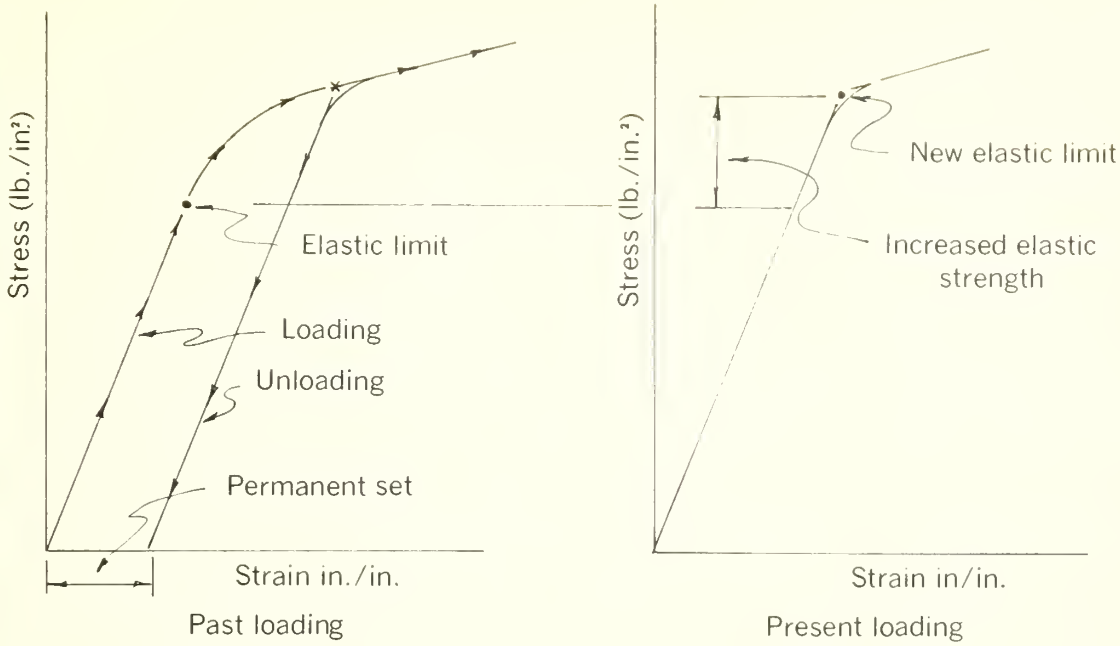


Figure 8.--Idealized stress-strain diagram.

In-Service Evaluation and Conclusions

The unit was installed with a quick-disconnect flexible coupling on the pump side to provide ease in checking and adjusting the no-load output.

Initial tests indicated some temperature sensitivity during the first few minutes of each test period, probably due to heat generated by the motor or the dynamometer circuitry. A warmup period of approximately 5-10 minutes was necessary to provide a stable temperature at which repeatability well within the desired ± 1 percent of full-load output was obtained.

Some drift in the no-load output signal was occasionally noticed after long testing periods of 30 minutes or more. The cause of this drift was not determined, but it was avoided by interrupting such long tests and checking and adjusting the no-load output signal during the run.

Table 1 presents typical data on pump performance results obtained during the testing program.

The photoelectric principle is very effective in detecting slight angular displacement caused by torsional loading of a rotating shaft.

The circuitry of the unit is temperature sensitive to some degree; the unit should be operated for a short warmup period, and used in an area that remains at a relatively constant temperature during a testing sequence. Periodic checks of conditions of no load should be made to insure an accurate indication of voltage change due to shaft loading.

Circuitry changes, using electronic components of greater temperature stability, would undoubtedly be possible to reduce or eliminate the temperature fluctuations should higher precision be desired for similar investigations.

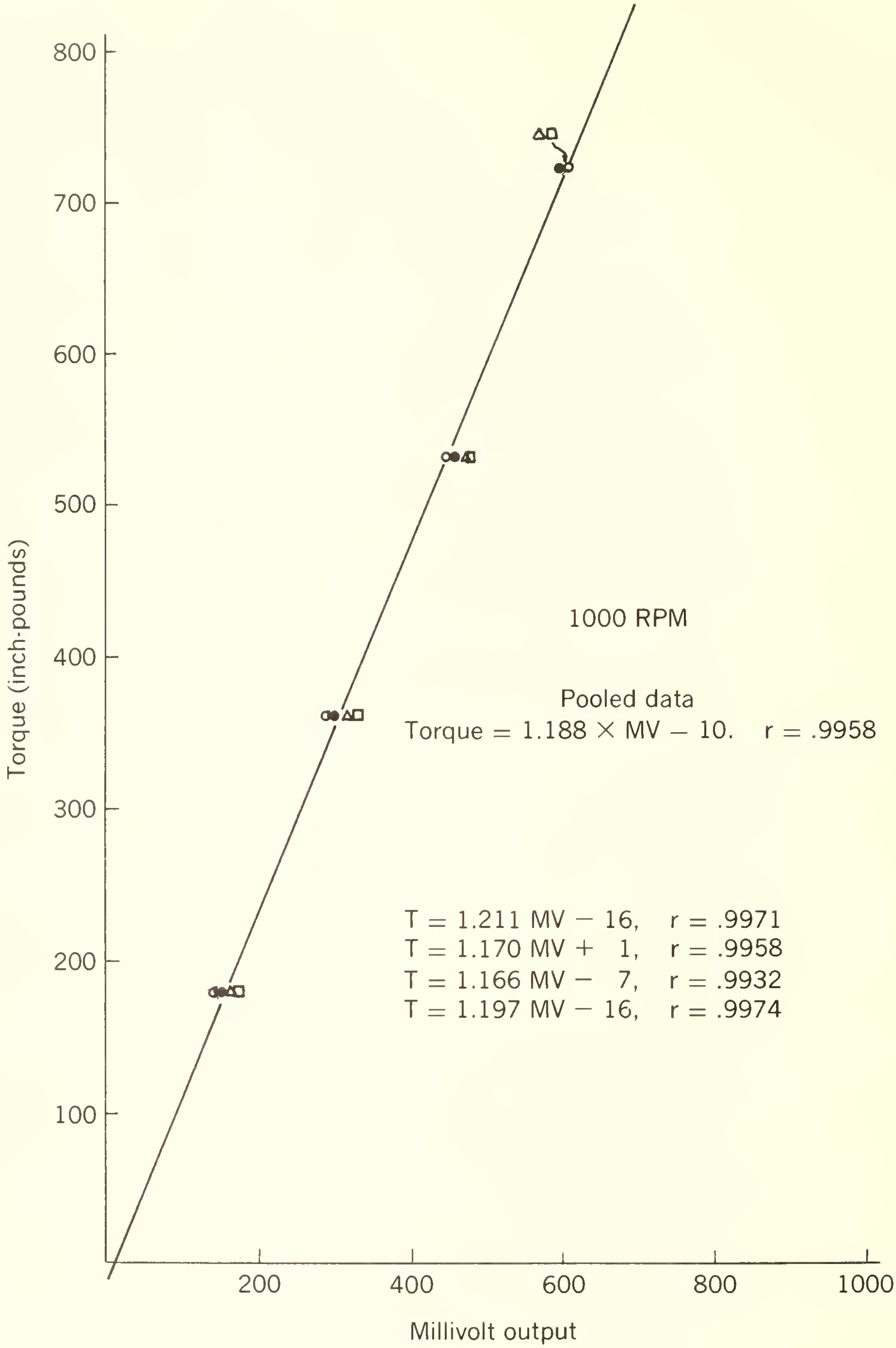


Figure 9.--Dynamometer output vs. torque.

Table 1.--Preliminary test data at nominal pump speed--1,150 r.p.m.[1]

Pump speed	Flow rate	Torque output	Differential pump pressure
R.p.m.	G.p.m.	Millivolts	Inches of mercury
1,155	500	249	25.2
1,159	450	239	27.3
1,153	400	224	28.4
1,156	350	212	30.1
1,150	300	198	31.1
1,154	250	182	33.0
1,156	200	166	34.1
1,150	150	149	35.1
1,148	200	164	33.8
1,156	250	183	33.1
1,154	300	198	31.3
1,153	350	210	29.9
1,150	400	224	28.3
1,149	450	236	26.7
1,149	500	245	24.9

[1]Initial no-load torque reading, 0 millivolts; final no-load torque reading, +2 millivolts.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

U.S.D.A. Forest Service
Research Note INT-83 1968

FACTORS THAT AFFECT CHOICE OF SHELVING MATERIALS IN SINGLE-FAMILY HOMES

Robert E. Benson and John R. Host[1]

ABSTRACT

Survey of homebuilders shows that lumber is predominant material used for shelving in single-family homes but builders have considerable interest in other materials such as particleboard and metal in order to eliminate warp and reduce installation and finishing costs.

Lumber has traditionally been the most common material used for shelving, but in recent years several alternate materials have been developed or adopted as substitutes. These include particleboard and plywood, which use wood in different form, and metal, which directly competes with wood.

Particleboard utilizes wood residues, species, and grades that are often difficult to market profitably as lumber. Low grade boards overlaid with plastic, paper, or similar material might yield a higher profit margin when sold for shelving than it would when sold as commodity lumber. Residential construction alone represents a potential annual market of over 100 million board feet for shelving material; this is based on 1.5 million housing starts.

The purpose of this study is to identify variations in use of shelving materials, to determine criteria builders use in selecting shelving, and to evaluate how well wood products measure up to those criteria. It is based on personal interviews with 136 builders located in 20 cities throughout the Nation, and includes shelving installed in 9,146 homes built either during 1965 or 1966. Shelving purchased as part of units, such as kitchen cabinets or bathroom vanities that were built off the site, are not included.

---

[1]Respectively, Associate Market Analyst and Research Forester, stationed at Forestry Sciences Laboratory, Missoula, Montana.

MATERIALS USED FOR SHELVING

Lumber accounted for most shelving installed by builders interviewed, although materials vary among specific applications (table 1). Lumber predominates in all applications, but plywood is sometimes used for wider shelves in linen and storage closets.

Ponderosa pine and white pine accounted for most lumber shelving, although builders in several southern cities often used southern pine, while hardwood lumber was occasionally used for bookshelves.

Particleboard was used more often by large volume builders: about 33 percent of those who built over 50 houses per year used particleboard as compared with only 5 percent of those who built under 50 houses.

Table 1.--Shelving materials used in single-family homes

Material	Bedroom and coat closets	Linen and storage closets	Kitchen[1]	Book shelves	Garage & utility
	Percent[2]				
Lumber	57	47	58	66	43
Particleboard	34	34	37	21	31
Plywood	1	11	4	3	5
Metal	8	8	1	10	21

[1] Does not include shelving in factory-built cabinet units.
[2] Based on material used by each builder weighted by number of houses he built.

RANKING OF FACTORS INVOLVED IN SELECTION OF MATERIAL

Builders consider a number of different criteria when they select shelving materials, and these factors are not rated equally important by all. Builders ranked these as follows:

	Most important (Percent)	Second most important (Percent)
Purchase price of shelving	37	15
Stability and durability	19	15
Installation and finishing	13	19
Home buyers' preferences	10	6
Width and length requirements	10	7
Other factors	11	9

Among builders who use lumber for shelving, the most important factors are (1) price, and (2) stability-durability. However, users of metal shelving ranked installation and finishing as most important; users of particleboard rated stability well ahead of other factors; and plywood users considered width requirements as the key factor.

COST COMPARISON OF MATERIALS

Purchase price of shelving ranged from as little as 9 cents per foot for southern pine lumber to over $1 per foot for some prefinished metal shelving.[2] The average purchase prices for shelving materials follow:

	Average purchase price ($/sq.ft.)
Lumber--select and No. 1 and No. 2 common ponderosa and white pine	0.21
Lumber--all other	.14
Particleboard	.22
Plywood	.19
Metal, prefinished	.82

Total installed costs for shelving also vary considerably, ranging from $0.18 per foot to over $3 per foot. Cost information on installing metal, plywood, or particleboard was too limited, however, to make any meaningful analysis of total cost for these materials. Many builders indicated they considered costs of installing and finishing shelves as part of the total closet cost; they did not have data on installation costs, only on price of material.

BUILDERS' COMMENTS ON MATERIALS

Lumber.--Major advantages reported on lumber are workability and ease of installation. Carpenters are familiar with lumber, and cutting and fitting is simple. Some builders feel that having to paint shelving is a disadvantage, but they consider lumber an easy material to paint or stain. Usually no separate edging strip is required on lumber since it has a smooth edge. On long shelves, however, some builders use a 1- by 2-inch strip of lumber to reduce sagging. Some apply a pattern moulding for appearance.

Installation and finishing costs for lumber shelving were not available from all builders, but the average cost reported was about 27 cents per foot for installing and about 15 cents per foot for finishing. These costs varied considerably. Builders who used higher grades of lumber (selects and No. 1 and No. 2 commons) reported costs averaged 38 cents for installing and 21 cents per foot for finishing as compared with average costs of 14 cents for installing and 9 cents for finishing among builders using No. 3 common and unspecified species and grades of lumber. No specific reasons for these differences were cited but builders who went to the extra expense of using high grade lumber probably put more effort into fitting and finishing. The average cost for lumber shelving is summarized:

	Select and No. 1 and No. 2 common pine ($/sq.ft.)	No. 3 common pine and unspecified grades and species ($/sq.ft.)	All Lumber ($/sq.ft.)
Purchase price	0.21	0.14	0.18
Installing	.38	.14	.27
Finishing	.21	.09	.15
Total	.80	.37	.60

[2]Most lumber shelving is nominally 12 inches wide; therefore, square foot and board foot are used synonymously in this report.

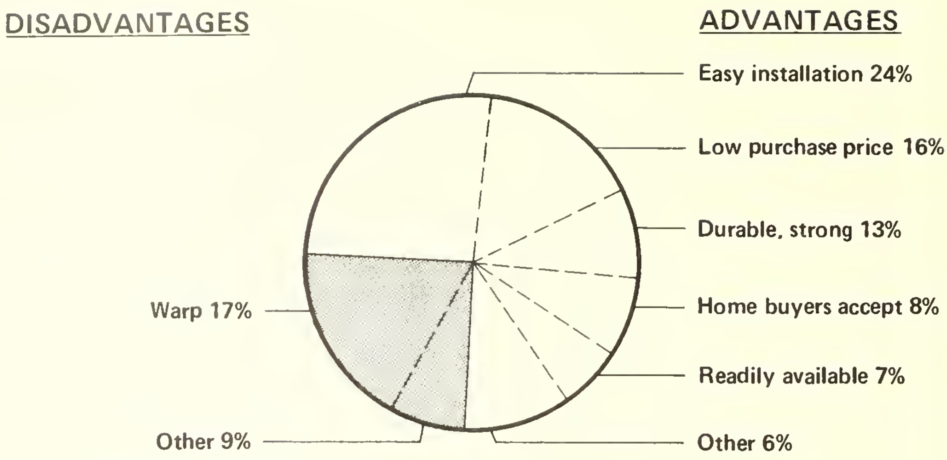


Figure 1.--Builders' comments on lumber shelving.

Many builders indicated that, aside from the actual physical properties of lumber, the image of strength and solidness is a factor in home buyers' acceptance of lumber shelving. Even when knots are visible, some buyers prefer "solid" lumber to an "imitation" material.

Two other factors also favor lumber: (1) it is readily available, and (2) it has many uses on building sites.

The major problem with lumber is warping. Even when lumber is nailed down, it has a tendency to warp. Warping poses even greater problems for those builders who prefer to install shelving "loose lay" so it can be removed easily for cleaning. Some other disadvantages reported are (1) that two boards are required for shelves wider than 12 inches, and (2) that torn grain, knots, and splits make it difficult to get a smooth-finished surface on lumber shelving. Builders' comments on lumber shelving are summarized in figure 1.

Particleboard.--This material has been accepted for shelving because it is comparable to lumber in price and workability and superior to lumber in terms of warping. It is considered easy to cut, fit, and install, and some builders feel that the absence of knots and splits makes it easier to use than lumber.

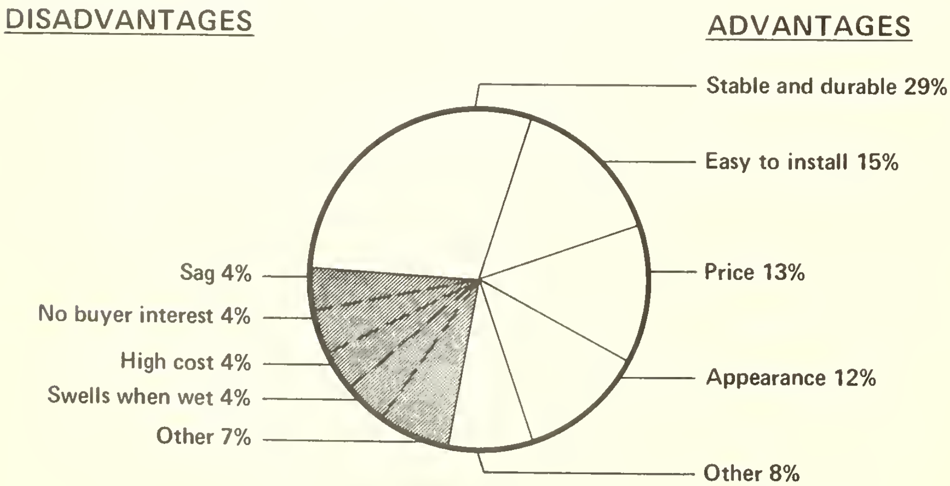


Figure 2.--Builders' comments on particleboard shelving.

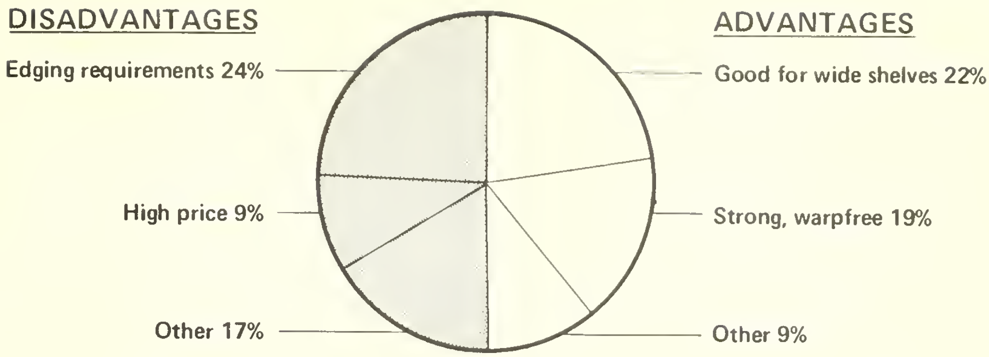


Figure 3.--Builders' comments on plywood shelving.

Some builders realize a cost saving in using particleboard because they do not apply a finish on this material. Those who do finish particleboard indicate that it paints or stains readily and presents a good appearance. An additional saving in labor was reported by some builders who use a particleboard with round nosing machined on at the factory or by their supplier. This eliminates the need for edging on the site. However, some builders feel an edging strip is needed to stiffen the particleboard shelving for long spans. Builders' comments on particleboard shelving are summarized in figure 2.

Plywood.--A major advantage of plywood is that a single piece of material can be used for shelves wider than 12 inches. Plywood is used for shelving mostly in linen and storage closets where 18- and 24-inch widths are common. Another advantage is that plywood is less subject to warp. Also, a few builders believe it is stiffer than lumber; therefore, it can be used for longer spans.

The chief drawback of plywood is that an edging strip is usually required to cover rough edges and voids in the inner plies. Some builders complained that the plies split when the edging strip is nailed. Several also stated that plywood surfaces are rough; therefore, they are more difficult to finish.

The average purchase price of plywood is about the same or less than that for higher grades of lumber. However, builders who use low grade lumber consider plywood expensive by comparison. Not enough data on installing and finishing costs for plywood were obtained to permit us to make a cost comparison with lumber. A few builders commented that the average installed costs for plywood and lumber shelving are about the same. Builders' comments on plywood shelving are summarized in figure 3.

Metal.--Builders' comments generally were more unfavorable than favorable with regard to metal shelving. However, metal has two major advantages over wood shelving. Installation is simplified in that metal shelves can be purchased ready to fasten into place; thus no cutting or finishing is required. In addition, metal shelves are warpfree.

The principal disadvantage is that metal shelves are not readily accepted by buyers. Builders reported that buyers feel metal shelves have a "tinny" look that does not give an image of being strong and solid. In addition, some report that metal shelves rattle when closet doors are closed unless the shelf has enough of a load on it to prevent vibration.

Another drawback is that metal shelving costs more. Builders usually do not keep detailed records of their shelving installation costs; therefore, they are more aware of the difference in purchase price between metal shelving and lumber. Moreover, prices for different quality metal shelves vary widely. Builders' comments on metal shelving are summarized in figure 4.

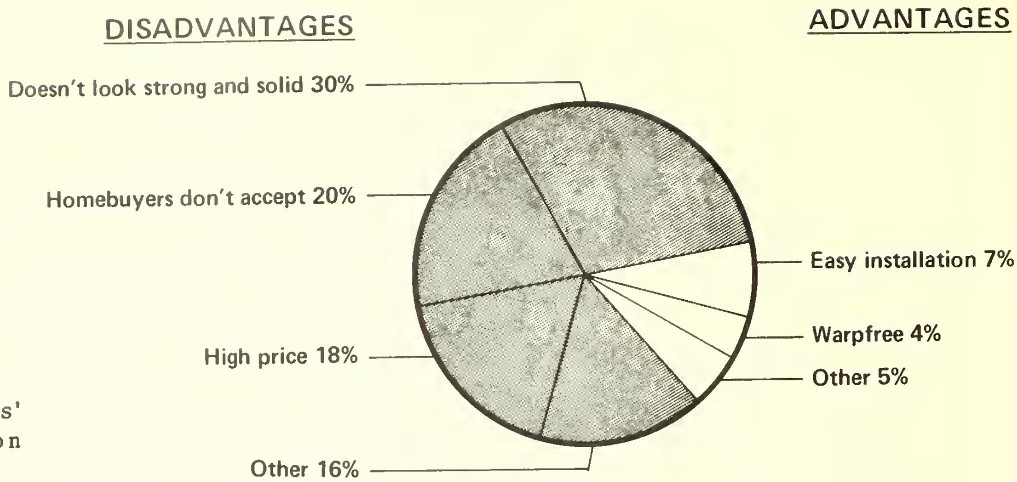


Figure 4.--Builders' comments on metal shelving.

CONCLUSIONS

Builders are interested in new shelving materials. Some have already changed from lumber to plywood, particleboard, or metal for some or all of the shelves they install. Others are seeking information on new products that might have better performance properties than lumber or that might reduce labor costs for installing and finishing.

Performance improvements suggested by this study are to overcome problems of warping, sagging, and surface defects. Particleboard is an example of an improved shelving material in that it is warpfree and has a smooth uniform surface.

Potential cost savings cited by builders would be to reduce or eliminate the time and labor needed for cutting, installing, and finishing shelving materials. Metal shelving offers one approach to such cost savings through a shelving "package"; that is, metal shelves are manufactured to size, prefinished, and the package includes all the necessary accessories and hardware for installation.

Conceivably the concept of a "package" system for cost saving might be extended to the entire closet. Many builders do not think in terms of shelving costs alone but rather in terms of total costs for closet or storage areas, and some feel that the cost of building closets is high relative to the low interest home buyers have in closets.

Perhaps the greatest obstacle to successful marketing of new shelving products is the fact that builders now tend to use purchase price of the material as the basis for comparing shelving cost. Lumber, which is low in cost, is often used as the "measuring stick." Therefore, to be successfully marketed, improved shelving products or shelving systems would have to offer a definite cost saving to the builder.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

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

U.S.D.A. Forest Service
Research Note INT-84 1968

MINERAL CONTENT AND PYROLYSIS OF SELECTED PLANT MATERIALS[1]

Charles W. Philpot[2]

ABSTRACT

Recent studies of pyrolysis of plant materials indicate that the rate of thermal degradation and the amount of volatile materials formed are directly related to the silica-free ash content (SFA) of the material. However, plants with SFA above 12 percent that were tested did not fit these relationships. Evidence was found that only certain constituents of SFA are effective in inhibiting pyrolysis.

Recent work on pyrolysis of cellulose contaminated with inorganic compounds has led to the conclusion that the flammability of plant material is influenced by the presence of inorganic materials (6).[3] Broido and Nelson (1) found that naturally dried and leached corn leaves were more flammable than unleached leaves because of differences in inorganic composition. Tamarix species was found to be fire resistant, presumably due to its extremely high mineral content (7). Since the mineral content of growing plants could drastically influence their combustibility, there is a possibility that "fire resistant" plants may be cultivated for specific geographic locations (4). Also, the chemical composition of different fuels may be quite important in predicting their flammability and should therefore be included in fuel evaluation systems.

Cellulose, the major component of plant material, apparently pyrolyzes by at least two different pathways. At low temperatures thermal decomposition provides CO, CO_2, H_2O and a charred residue that supports glowing combustion (4). At high temperatures, degradation of the macromolecules gives a large variety of low-molecular-weight organic compounds that support the flaming combustion (5). Treatment of cellulose with

---

[1]Research sponsored in part by the Department of Defense, ARPA Contract 818. This publication has been approved for open distribution.

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

[3]Numbers in parentheses refer to Literature Cited.

inorganic flame retardants, such as $(NH_4)_2HPO_4$, $ZnCl_2$, and $KHCO_3$, increases the char formation at the expense of the flammable, volatile compounds. Minerals present in plants have the same effect. On this basis, hazard rating of natural fuels and selection of more fire resistant plants should include consideration of chemical composition as well as physical properties. Several plant species are being studied for this purpose.[4] In the present study, several plant materials with ash contents ranging from 0.11 to over 27 percent were investigated by thermogravimetric analysis (TGA). A variety of species was used to get a broad range of mineral contents, not to assess the fire characteristics of the species itself.

The plant materials tested were:

"Ash-free" cellulose, 1[5]

Wood: Pseudotsuga menziesii, 2

Betula sp., 3

Pinus ponderosa, 4

Populus sp., 5

Grass: Bromus tectorum, 6

Elymus caput-medusae, 7

Needles: Pinus ponderosa, 8

Pinus monticola, 10

Twigs: Adenostoma fasciculatum, 9

Leaves: Adenostoma fasciculatum, 11

Populus tremuloides, 12

Psidium guajava, 13, 14, 15

Atriplex canescens, 16

Tamarix aphylla, 17

Atriplex polycarpa, 18

Atriplex lentiformis var. brewerii, 19

Atriplex nuttallii var. gardnerii, 20

Atriplex gardnerii, 21

---

[4]Work being done at U.S.D.A. Forest Service, Forest Fire Laboratory, Riverside, California.

[5]Numbers refer to those used in figure 1.

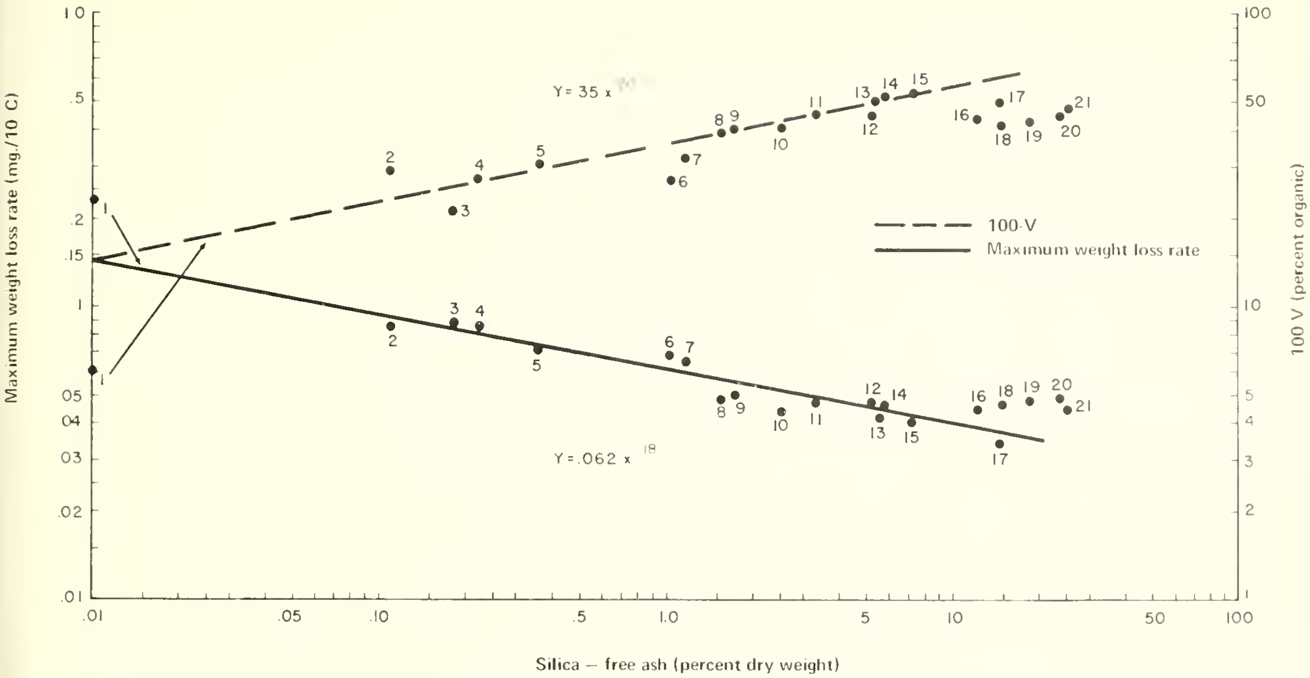


Figure 1.--The relationships between maximum weight loss rate and 100-V, and SiO_2-free ash.

The plant material was dried, ground to pass 40 mesh and be retained by 60 mesh, and analyzed for total ash and silica content.[6] The total Ca, Na, and K was determined by flame photometry and P and Fe were determined by colorimetry. All chemical analyses except for SiO_2 were performed after wet digestion with a ternary acid mixture. Ten-mg samples were used in a DuPont[7] model 950 thermoanalyzer in a stream of N_2 at 100 cc./min. and a heating rate of 15°C./min. All experiments were set electronically to record percent weight loss after the moisture was driven off. Three replications were made on each species.

Following the lead of Browne and Tang (2), differences in the pyrolytic reactions and reaction products were judged according to two criteria: maximum weight loss rate during active pyrolysis and total weight loss during pyrolysis from 175° to 350°C., or V, when expressed as a percentage of original organic matter present. Active pyrolysis of these fuels ceased at 350°C., above which only very small weight loss occurred. All weight is expressed as percent of original organic matter.

The results shown in figure 1 indicate that for these samples the rate of pyrolysis is inversely related to silica-free ash content up to 12 percent (dry weight). The SiO_2 content has been deducted from the ash because it has been shown to have little, if any, effect upon pyrolysis.[8] A direct relationship holds for 100-V when V is the

---

[6]ASTM Standards, D1102-56, Methods of test for ash in wood. Assoc. Offic. Agr. Chem., Methods for Analysis, 6.005. 1965.

[7]Use of trade names herein is for identification and does not imply endorsement by the U.S.D.A. Forest Service.

[8]Mutch, R. W., and C. W. Philpot. High ash content: not always equated with low flammability. Intermountain Forest and Range Exp. Sta. (In preparation.)

weight lost by the organic materials from 175° to 350°C. The plants that show the largest deviation are all of the genus *Atriplex*. These plants have been suggested as being fire resistant due to high mineral content. *Tamarix* showed the lowest maximum weight loss rate, which further substantiates the work of Waisel and Friedman (7).

The mineral analysis showed that Na content of the *Atriplex* tested ranges from 0.18 to 8.46 percent, and the K content ranges from 1.03 to 4.68 percent. For example, *A. gardnerii*, 21, has 8.46 percent Na as compared to the 0.1 percent or less for the other genera and 28 times that of *Tamarix*. *A. canescens*, 16, has a K content of 4.68 percent or eight times that of *Tamarix*. The P content of the *Atriplex* ranges from 0.185 to 0.307 percent. The P content of *Tamarix* is 0.150 percent. This suggests that K and Ca have less effect on pyrolysis than does P. Despite higher silica-free ash content, *Atriplex* does not show any pyrolytic advantage over *Tamarix* as indicated by TGA data. Thus all ash constituents are not equally effective and total ash content should not be used to rate relative pyrolytic characteristics of natural fuels.

LITERATURE CITED

1. Broido, A., and Maxine A. Nelson.
   1964. Ash content: its effect on combustion of corn plants. Science 146: 3644, 652-653.

2. Browne, F. L., and W. K. Tang.
   1962. Thermogravimetric and differential thermal analysis of wood and of wood treated with inorganic salts during pyrolysis. Fire Res. Abstr. and Rev., Nat. Acad. Sci., Nat. Res. Counc. V. 4, 112, January and May.

3. Kilzer, F., and A. Broido.
   1965. Speculations on the nature of cellulose pyrolysis. Pyrodynamics 2(2): 151-163.

4. National Academy of Sciences.
   1961. A study of fire problems. Nat. Acad. Sci., Nat. Res. Counc., Comm. on Fire Res. Pub. 949, p. 80.

5. Schwenker, R. F., Jr., and L. P. Beck, Jr.
   1965. Study of the pyrolytic decomposition of cellulose by gas chromatography. J. Polymer Sci., Part C(2): 331-340.

6. Shafizadeh, F.
   1968. Pyrolysis and combustion of cellulosic materials. Advances in Carbohydrate Chemistry 23: 419-474.

7. Waisel, Yoav, and Jacob Friedman.
   1965. The use of *Tamarix* trees for the restriction of fires. Tel-Aviv Univ., Dep. Bot., Israel, 7 pp.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

U.S.D.A. Forest Service
Research Note INT-85

NATURAL REGENERATION OF DOUGLAS-FIR IN CENTRAL MONTANA

Charles R. Hatch and James E. Lotan[1]

ABSTRACT

Relations between Douglas-fir regeneration and seedbed surface conditions that influence natural restocking were analyzed. Undisturbed duff produced significantly greater number of seedlings per acre than five of seven seedbeds tested.

Douglas-fir stands less than 20 years old are practically nonexistent among timber stands east of the Continental Divide in Montana, where this species currently accounts for more than 40 percent (board-foot volume) of sawmill receipts (Wilson 1964).

We don't know why this problem of inadequate regeneration exists, only that it apparently has evolved in recent years. Before 1950, Douglas-fir established itself fairly regularly in cutover areas among these timber stands, and numerous examples are known where it had established itself in sagebrush types.

We do know Douglas-fir seedling germination and survival are highly dependent on favorable environmental conditions. Proper seedbeds aid in providing such conditions. This paper reports on a study of seedbed surface conditions and compares regeneration under seven different types of seedbed conditions 2 to 7 years after clearcutting.[2]

STUDY AREA

Six logged areas were selected for study on the Helena and Lewis and Clark National Forests both located east of the Continental Divide in Montana. All trees 13.1 inches d.b.h. and larger were harvested on the areas 2 to 7 years previous to study installation. On only one area of the six was all residual material felled following the initial cut. Slash was dozer piled and burned.

---

[1]Formerly Assistant Silviculturist, and presently Silviculturist, respectively, stationed in Bozeman, Montana, at Forestry Sciences Laboratory, maintained in cooperation with Montana State University. Hatch is presently Graduate Student at School of Forestry, University of Minnesota, St. Paul.

[2]Study was installed and data were collected by C. S. Billheimer, U.S.D.A. Forest Service, Northern Region, Missoula, Montana, and David Tackle, now with the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Stands harvested range in age from 150 to 400 years. An average tree is 18 inches d.b.h. and 80 feet tall, and the largest trees may attain the height of 110 feet.

All of the stands are heavily damaged by spruce budworm (Choristoneura occidentalis Freeman). The area is used extensively as summer range for cattle. Soils are classified as silt and clay loams.

Associated with Douglas-fir are the following species: lodgepole pine (Pinus contorta), whitebark pine (Pinus albicaulis), Engelmann spruce (Picea engelmanni), and subalpine fir (Abies lasiocarpa). Principal understory vegetation includes pinegrass (Calamagrostis rubescens), arnica (Arnica cordifolia), bedstraw (Galium spp.), strawberry (Fragaria virginiana), rose (Rosa spp.), Canadian buffaloberry (Shepherdia canadensis), and snowberry (Symphoricarpos spp.).

METHODS AND RESULTS

Reproduction was sampled at two chain intervals along line transects run across the slope. Each sample point consisted of four adjacent square-milacre quadrats. The following measurements were collected on each quadrat: estimated seedbed condition following logging; percent slope; aspect; number of seedlings by species; and percent stocking in terms of stocked milacre quadrats at each sample point. The seedlings established prior to and subsequent to logging were recorded separately, but only seedlings established after logging were analyzed. Reproduction was defined as trees up to and including 5.5 feet in height. The distribution of the various seedbed conditions was as follows:

Seedbed surface conditions	Milacre quadrats
Grass or herbs	116
Burned	35
Bare mineral soil	107
Brush	57
Disturbed duff	110
Logging slash	120
Undisturbed duff	43
Total	588

The seed source of the sample point was noted by recording estimated distance to nearest seed tree in each of four directions or distance to the nearest timber edge. Seed traps were placed near one of the logged areas in two different years to obtain a measure of the stand's present capacity to produce seeds. Residual stand measurements included height, diameter, radial growth, and age. Soil samples were taken on each area.

Data were analyzed using techniques assuming that sampling units were randomly distributed. Systematic sampling was used instead of random sampling because of the ease of location of sampling units.

Eighty-one percent of all seedlings were Douglas-fir. Little correlation was found to exist between Douglas-fir seedlings and the measured topographic, edaphic, and stand factors. The best multiple regression equation accounted for only 26 percent of the variation in percent of Douglas-fir stocking. Independent variables that explained most of the variation included distance to seed source, years since logging, growth and basal area of residuals, and aspect.

Table 1.--Average Douglas-fir seedlings per acre on various types of seedbeds

Seedbed surface conditions						
Grass or herbs	Burned	Bare mineral soil	Brush	Disturbed duff	Logging slash	Undisturbed duff
95	114	140	316	382	825	1,140

[1]Means underscored by the same line are not significantly different.

A significant difference was shown between numbers of Douglas-fir seedlings per acre on various types of seedbeds (table 1). Percent Douglas-fir stocking was significantly different on the north and south aspects (20 and 8 percent, respectively). There were no significant differences in stocking between the north and east or between east and south aspects. The number of seedlings per acre on the north, east, and south slopes was 368, 524, and 102, respectively.

On the area where the seed traps were placed seed production was estimated to be 360,000 (1957) and 48,000 (1958) sound seed per acre annually in the uncut timber.

DISCUSSION AND CONCLUSIONS

Results obtained in this study permit conclusions that closely parallel observations noted for Douglas-fir regeneration in the Southwest (Krauch 1956). Central Montana and the Douglas-fir country near Cloudcroft, New Mexico, where Krauch studied this species, are remarkably similar climatically from June to September (Krauch 1956; U.S. Weather Bureau 1965), as shown in table 2. The same variety of Douglas-fir is found on both areas, although in the Southwest the Douglas-fir type is found at elevations ranging from 8,000 to 9,500 feet, as compared to 5,000 to 7,000 feet in central Montana.

Table 2.--Climatic conditions for central Montana and near Cloudcroft, New Mexico

Location	Temperature[1]			Precipitation[1]
	Mean	Mean maximum	Mean minimum	Mean
	Degrees	Degrees	Degrees	Inches
Central Montana	55.3	70.0	40.6	25
Near Cloudcroft, New Mexico	57.0	70.3	43.7	26

[1]For months of June, July, August, and September.

Douglas-fir stocking was significantly lower on the south aspect than on the other aspects. Higher soil surface and air temperatures associated with southern aspects would probably reduce soil moisture and increase susceptibility due to heat injury. Lack of variation on the study areas and number of sample points permitted only a general analysis of aspect and slope in terms of seedling establishment.

Stocking was best on either undisturbed seedbeds or those covered by logging slash. The litter present in undisturbed duff is important in Douglas-fir regeneration for several reasons: it conserves soil moisture, reduces herbaceous vegetation, and protects the seed from rodents and birds (Krauch 1956).

Logging slash provides shade without competing for soil moisture. Shade is an important factor because Douglas-fir seedlings are susceptible to heat injury during the first year (Krauch 1956; Isaac 1938). Shade not only reduces soil surface temperature, it also conserves soil moisture, reduces herbaceous vegetation, regulates seedling transpiration (Krauch 1956), and protects the seedlings from cattle, although this was not determined in the study.

The best variables in the multiple regression equations dealt with quantity of seed placed on the areas. Thus, it would seem that future research should be directed toward factors that influence the quantity of seed reaching the ground. The effects of cone and seed insects and defoliation by spruce budworm also should be studied.

For example, spruce budworm was prevalent in the stands and no doubt influenced the amount of viable seed dispersed on the area. In addition, seed and cone insects probably had a detrimental effect on seed production. We already know rodent and bird populations can be a determining factor in natural regeneration (Krauch 1945, 1956; Smith and Aldous 1947).

LITERATURE CITED

Isaac, Leo A.
1938. Factors affecting establishment of Douglas-fir seedlings. U.S. Dep. Agr. Circ. 486, 45 pp., illus.

Krauch, Hermann.
1945. Influence of rodents on natural regeneration of Douglas-fir in the Southwest. J. Forest. 43: 585-589.

______
1956. Management of Douglas-fir timberland in the Southwest. U.S. Forest Serv., Rocky Mountain Forest & Range Exp. Sta. Pap. No. 21, 59 pp., illus.

Smith, Clarence F., and Shaler E. Aldous.
1947. The influence of mammals and birds in retarding artificial and natural reseeding of coniferous forests in the United States. J. Forest. 45: 361-369.

U.S. Weather Bureau.
1965. Decennial census of United States climate, climatic summary of the United States, supplement for 1951 through 1960. Climatography of the U.S. No. 80-20, Mont., 112 pp.

Wilson, Alvin K.
1964. Output of timber products in Montana, 1962. U.S. Forest Serv. Res. Pap. INT-11, 10 pp., illus.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

U.S.D.A. Forest Service
Research Note INT-86

1969

ABERRANT CONES IN WESTERN WHITE PINE

R. T. Bingham, K. C. Wise, and S. P. Wells[1]

ABSTRACT

Two rare cone forms--proliferated and forked--are reported and illustrated for Pinus monticola. The latter form may be unique to this species, and may be genetically controlled. In addition, genes controlling the "forked-cone" trait may be linked with recessive genes associated with chlorophyll deficiencies of P. monticola foliage.

We have found two rare cone forms in western white pine (Pinus monticola Dougl.). These aberrant forms were found among the more than 70,000 female cones observed on over 1,500 trees, in the course of our 18 years of research into the nature of blister rust resistance in that pine species.

The first of these forms (fig. 1)--the so-called proliferated cone--has long been known for a variety of conifers. Doak (1935) listed 11 references wherein the authors mentioned 12 or more conifer species (including Pinus spp.) found to have various modifications of this cone form. Chamberlain (1935, fig. 299) illustrated proliferated cones of Larix and Cryptomeria, as did Looney and Duffield (1958, fig. 1) for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco).

Occurrence of proliferated cones in two other species has been verified by two other members of our staff: in tamarack (Larix laricina (Du Roi) K. Koch) by G. E. Rehfeldt, and in black spruce (Picea mariana (Mill.) B.S.P.) by D. O. Coffen. In addition, LeRoy Johnson of the Institute of Forest Genetics, Placerville, California,[2] has sent us a proliferated cone of Aleppo pine (Pinus halepensis Mill.). Probably proliferated cones remain unreported for many other conifers.

---

[1]Research Plant Geneticist and Forestry Research Technicians, respectively, stationed in Moscow, Idaho, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho.

[2]A field unit of the U.S. Dep. Agr., Forest Serv., Pacific Southwest Forest and Range Experiment Station.

Figure 1.--Proliferated cone of western white pine.

Despite the fact that proliferated cones are known for so many conifers, their occurrence remains a rarity. For instance, in 25- to 70-year-old western white pine observed closely for periods of from 5 to 18 years, we have found them on only three or four out of 500 trees. They seem to occur with about the same frequency on 8- to 16-year-old trees (on seven out of 1,000 trees) growing in a Moscow, Idaho, arboretum.

The second aberrant form--forked cones (fig. 2)--may be heritable. While we have found forked cones on only eight western white pines, two of these trees have borne forked cones in successive years. Furthermore, the only two trees in the arboretum at Moscow that have borne forked cones are very closely related; they are full-sibs coming from a controlled cross pollination.

Perhaps even more intriguing is our observation that in western white pine gene(s) controlling the forked-cone trait may be linked with those controlling pigmentation of the foliage. Four of the eight trees known to carry the forked-cone trait have been self-pollinated, and the two arboretum full-sibs known to carry the trait have been crossed. Progenies from the four selfings contained clearly defined 3:1 ratios of green:albino or yellow-green types. And the smaller progeny from the full-sib mating contained a somewhat less clearly defined 3:1 ratio of green:yellow-green types (28:8).

We have also considered the relationship of fasciation and forking of cones. This was because the forking of fasciated conifer shoots seems to be a fairly common occurrence (cf. fig. 13 in Hubert 1931; and fig. 1 in Duffield and Wheat 1963). In fact, Dr. Duffield has directed our attention to a ponderosa pine (P. ponderosa Laws., no. P-Eld-4A-22, growing on the grounds of the Institute of Forest Genetics at Placerville) that consistently, year after year, produces fasciated and apparently forked, male cones. E. J. Carpender and C. W. Busche of that Institute kindly have sent us dried male cones from this remarkable tree.

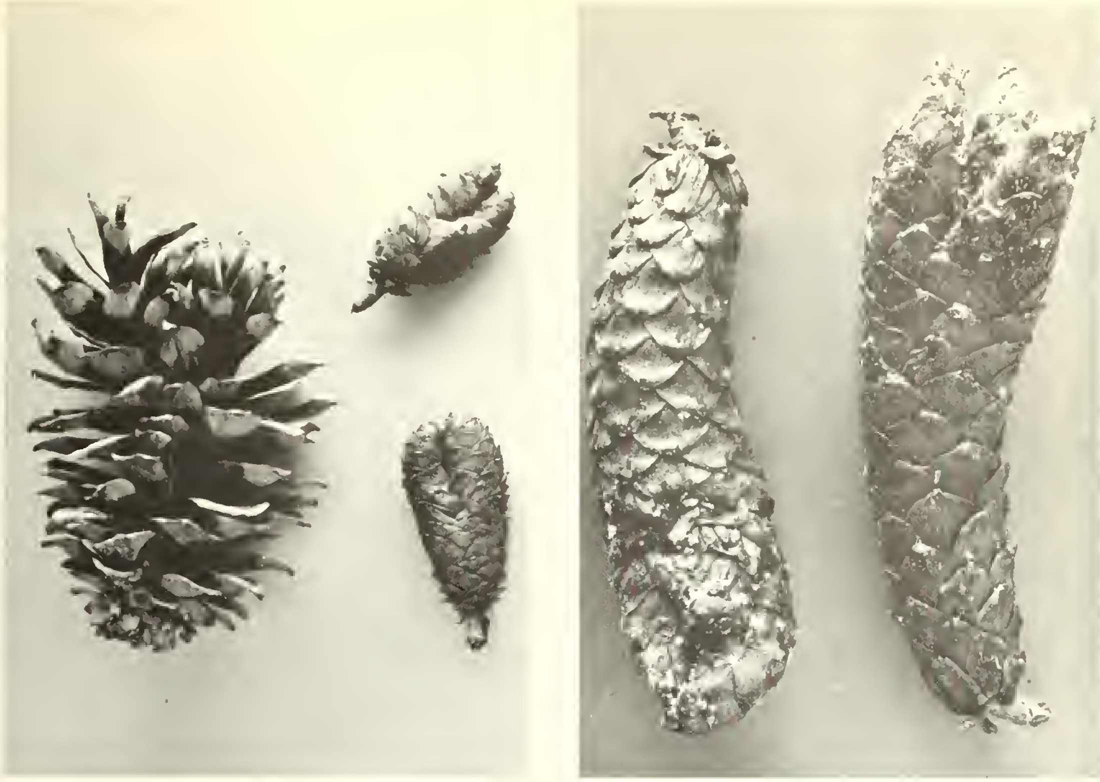


Figure 2.--Double- and triple-forked cones of western white pine.

Outwardly, these male strobili appear to be frequently and conspicuously forked (upper half of fig. 3). But when the microsporangia are removed it becomes apparent that the fasciated cone axes, rather than forking, merely have separated or split apart (lower half of fig. 3). Certain of the fasciated axes have remained intact (fig. 3A); others have partly separated, apparently along lateral fracture lines first developing in the middle portion of the axis (fig. 3C); and still others have split longitudinally, one or more times, separating along their entire length (fig. 3B and D). Mechanical splitting rather than true forking seems to be the case, since sterile surfaces are visible along the lateral fracture lines (lower half of fig. 3B, C, and D).

Close examination of our forked P. monticola female cones, however, fails to disclose any fasciation or splitting of the axes. Distad of the forks the cone axes are normal and fertile on all sides.

LITERATURE CITED

Chamberlain, Charles Joseph.
1935. Gymnosperms, structure and evolution. 484 pp. Chicago: Univ. Chicago Press.
Doak, Clifton Childress.
1935. Evolution of foliar types, dwarf shoots, and cone scales in Pinus, with remarks concerning similar structures in related forms. Univ. Ill. Bull. 32(49): 1-106.
Duffield, J. W., and J. G. Wheat.
1963. A common fasciation in Douglas-fir. J. Hered. 54(5): 240-242.
Hubert, Ernest E.
1931. An outline of forest pathology. 543 pp. New York: John Wiley and Sons, Inc.
Looney, William S., and John W. Duffield.
1958. Proliferated cones of Douglas-fir. Forest Sci. 4(2): 154-155.

Figure 3.--Fasciated male strobili of ponderosa pine, below with the microsporangia removed.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-87

1969

THE HYGROTHERMOAEROGRAPH--CONSTRUCTION AND FIRE MANAGEMENT APPLICATIONS

William C. Fischer, William R. Beaufait, and Rodney A. Norum[1]

ABSTRACT

Conventional hygrothermographs can be modified as described here to record windspeed along with temperature and relative humidity. The fire-weather record resulting from the modification has several fire management applications, as demonstrated in field use.

Fire management skill is acquired through understanding of the changing relations of weather, fuels, and fire behavior. In planning the control of wildfires and the conduct of prescribed fires, fire managers are dealing with a dynamic atmosphere of varying windspeed, relative humidity, and temperature. Continuous monitoring of these weather parameters can provide essential data for guiding fire management decisions. A readily available and portable monitor is the hygrothermograph. Its value as a tool for fire management has long been recognized (Hofman and Osborne 1923). The limitations of hygrothermographs as weather recording instruments have also been documented (MacHattie 1958; Hayes 1942). However, if these limitations are known and individual units are properly calibrated by qualified personnel and frequently checked for adjustment (Hardy et al. 1955), their accuracy can approach that of sling psychrometers. Of much greater value to the fire manager, however, is the record they provide of recent weather trends.

To make the instrument more useful in fire management, we modified conventional hygrothermographs (HTG) to record windspeed along with temperature and relative humidity. To describe their function more completely we call them hygrothermoaerographs (HTAG). An HTAG is shown in figure 1.

HYGROTHERMOAEROGRAPH CONSTRUCTION

Adaptation of hygrothermographs to record windspeed is not new. Our HTAG's represent refinement of a similar unpublished modification by Austin E. Helmers, developed in conjunction with hydrologic studies on the Priest River Experimental Forest during the period 1949-1951. Units patterned after this modification are currently in service at several weather stations in southern Idaho. Helmers also added a wind record pen to a 12-inch dual traverse recording rain gage as an aid in interpreting precipitation catch records.

---

[1]Respectively, Forester, Principal Research Forester, and Physical Scientist, stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

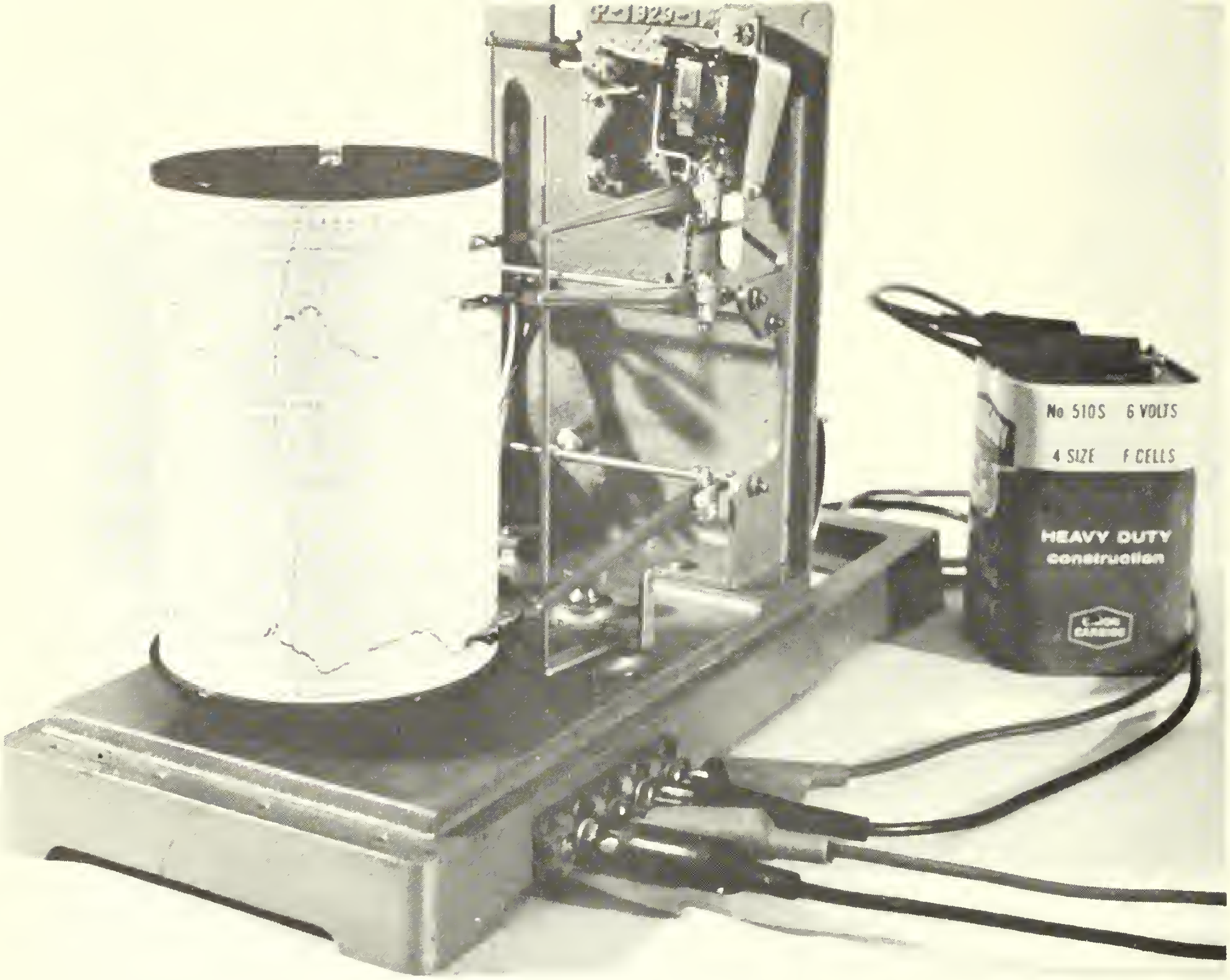


Figure 1.--A hygrothermoaerograph (HTAG). Upper arm records wind movement as transmitted by a contacting, totalizing-type anemometer. (Cover removed for photo only.)

Reigner (1964) described a method for adapting any drum-type recorder to obtain wind movement records. He proposed converting the hygrothermograph or rain gage to a wind movement recorder, rather than increasing the capability of these instruments.

Construction of an HTAG unit involves (1) modification of an anemometer; (2) construction and installation of the electrical circuitry; and (3) installation of an additional arm on a hygrothermograph. These tasks are well within the capability of most radio or electronic technicians employed by land management agencies. Necessary parts are available at a cost of approximately $9 from electronic supply houses. About 4 man-hours are required to make the conversion.

Anemometer Adaptation

The HTAG is designed for use with a contacting, totalizing-type anemometer. Both the Bendix[2] dial-totalizing type and the Belfort counter-totalizing type anemometers have been used successfully with our units (fig. 2). The extent of modification depends on the nature of readout desired. With the anemometers specified, it is possible to record every 1, 2, 5, or 10 miles of wind movement. For hygrothermographs with 24-hour charts we suggest obtaining a record of every 1 or 2 miles of wind. For those with weekly or monthly charts, a record of every 5 or 10 miles is more practical.

---

[2]Mention of trade or brand names is solely for convenience in identification and does not imply endorsement by the Forest Service.

Figure 2.--Anemometers: dial-totalizing type (left) and counter-totalizing type (right).

We prefer a record of every 5 miles of wind on weekly charts. To obtain the desired readout, the unnecessary pins must be removed from the 1-mile contact, which is on the outer dial of the dial-type anemometer, and on the contact wheel of the counter-type anemometer. The pins can be removed quite easily with pliers. Desired wind readout is accomplished as follows:

Record desired	Modification required
1 mile	Leave all 10 pins intact
2 miles	Remove every other pin
5 miles	Remove all but two opposing pins
10 miles	Remove all but one pin

Most totalizing anemometers contain a 1/60-mile electrical contact in addition to the 1-mile contact. Only the 1-mile contact needs the modification described above. The two circuits can operate simultaneously if the HTAG is to be used at a fire-danger rating station. The National Fire-Danger Rating System currently prescribes that a 10-minute average wind value be taken at the standard observation time. A standard counter wired to the 1/60-mile contact circuit of the anemometer will allow it to be used for this purpose. The Bendix-Friez, Small Airways, Stewart, Chisholm, and Forester type contacting anemometers (U.S.D.A. Forest Service 1964) contain only a 1/60-mile contact circuit. For this reason, we did not consider their use with HTAG's.

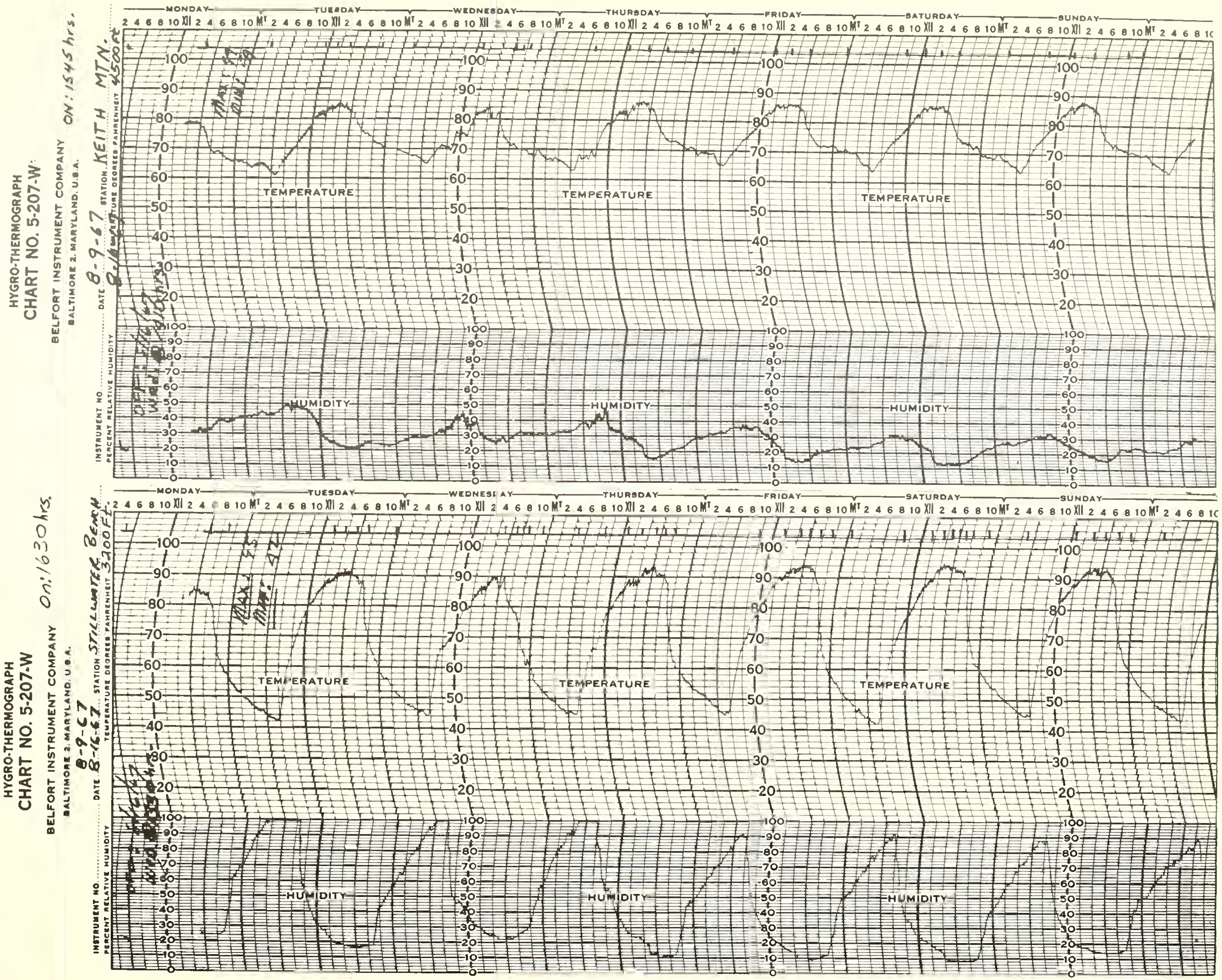
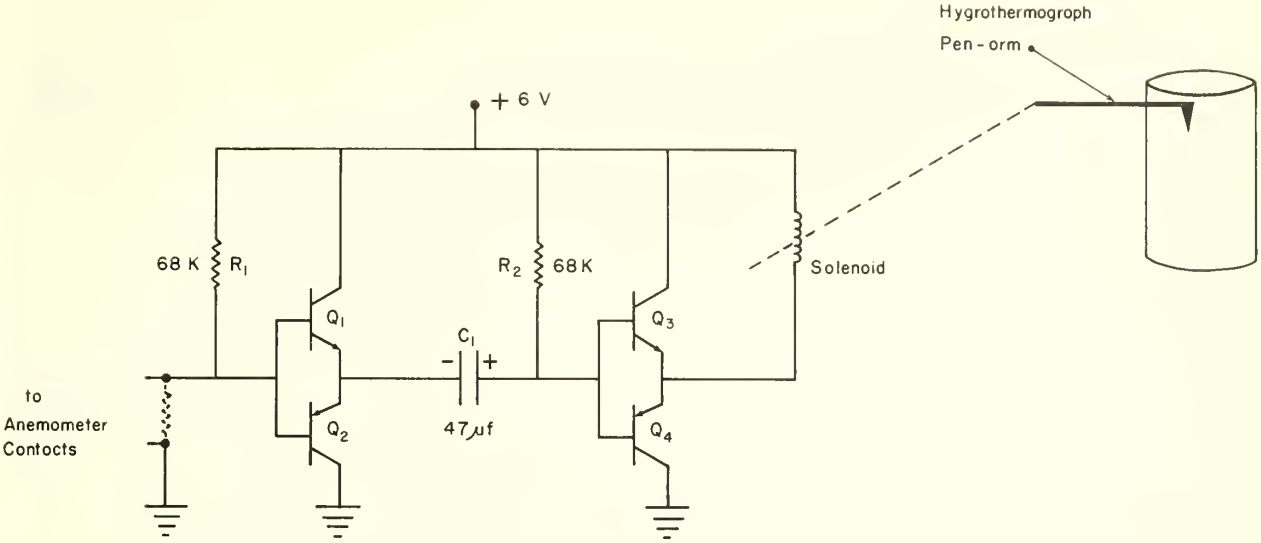


Figure 3.--HTAG charts showing windspeed (upper) trace in addition to temperature (middle) and relative humidity (lower traces).



Ports List

1 – Solenoid – D.C. Reloy; 200 ohm w/silver contocts. (SIGMA-200 or equivolent.)
2 – Resistors – R_1 ond R_2 = 68k, ± 10%; 1/2 wott.
1 – Copocitor – C_1 = 47 μf, 10 volt D.C.; ± 10%.
1 – Bottery – 6 volt, lontern type.
4 – Tronsistors – Q_1, ond Q_3; NPN FAIRCHILD S7581 or equivolent.
Q_2, ond Q_4; PNP G.E. 2N1303 or equivolent.

Figure 4.--Wiring diagram and parts list for adapting a hygrothermograph to record air movement past a totalizing anemometer.

The Electrical Circuit

The electrical circuit is designed to represent each 1, 2, 5, or 10 miles of wind movement as a short vertical line on the HTAG chart (fig. 3). Sustained windspeeds of 30 m.p.h. can be legibly recorded on a weekly chart using 5-mile contacts.

An electrical contact is made each time anemometer cups travel a given number of revolutions. To record the revolutions, a solenoid is connected in series with the anemometer contacts and a battery power source. In ordinary use, actuation of the solenoid serves to trigger any of a variety of counters; for the HTAG, it moves a pen arm.

To prevent premature battery failure, we inserted a monostable vibrator in the circuit (fig. 4) to provide a 2-second current pulse to the solenoid when anemometer contacts close. If the contacts remain closed at the end of the current pulse because of cessation of wind, less than 0.1 milliampere of current is drawn from the battery through a large input resistor. An even larger resistor could be used to reduce battery drain, but some older anemometers are constructed with insulating materials that may provide a path for leakage of current to ground. This possibility is shown in figure 4 as a dotted-line resistor across the contacts. Since this insulation is actually a resistor of about 120 K ohms, a voltage-dividing network is formed at the circuit input. The result is a reduction in amplitude of the initiating voltage and a decrease in the time duration of the solenoid current pulse.

The solenoid was mounted on the bulkhead in the hygrothermograph. The remaining circuitry can be mounted on an insulated circuit board and also attached to the bulkhead (fig. 5). Type F, 6-volt lantern batteries showed no decrease in operational efficiency after 3 months of use. However, proper polarity (fig. 4) must be observed to prevent destruction of semiconductors during use.

Installing the Pen Arm and Solenoid

The additional pen and pen arm assembly can be obtained from the hygrothermograph manufacturer. Installation instructions are listed below and illustrated in figure 5.

1. Fabricate pen arm mounting bracket and shaft B from scrap hardware and attach to hygrothermograph bulkhead A. Use 1/8-inch diameter steel rod for the shaft.
2. Slip windspeed pen arm assembly C on shaft B and lock in place. Make sure the pen extends the same length on the chart as the other two pens.
3. Fabricate solenoid mounting bracket D from scrap hardware and attach to bulkhead A.
4. Attach solenoid E to bracket D. See figure 4 for solenoid specifications.
5. Solder small wire loop F to solenoid arm.
6. Using fine, solid wire (about no. 24) form connecting link G and loop one end through solenoid loop F.
7. Loop lower end of connecting link G through hole drilled in pen arm tongue H. The length of connecting link G should be such that the windspeed pen tracks above the 104° line on the HTAG chart.

Very carefully solder closed the loops at the ends of connecting link G. The loops should not be soldered to the points of attachment as freedom of movement is necessary for smooth operation of the pen arm.

EXAMPLES OF HTAG USE

Prescribed Fire

The HTAG effectively met weather data needs of our forest fire scientists in a recent study of fire use. The study plan required installation of two fire-weather stations at different elevations within a drainage. Prescribed fires were scheduled at many times during both day and evening throughout the available burning season. Burning during the summer required specific knowledge of when daytime winds moderated and when humidity began its nighttime rise. In addition, fire-weather forecasters requested that observations be taken 24 hours before each burn.

Personnel were not available to man our stations at the odd hours required by this schedule. Commercially available telemetering and automatic recording weather stations were priced beyond study means. Hygrothermoaerographs offered a reasonable alternative.

Our HTAG's were mounted in standard Cotton Region shelters and were read as necessary to provide weather data required for computation of National Fire-Danger Spread and Buildup Indices and to meet spot forecasting needs. Recording rain gages provided the necessary precipitation data. When conscientiously calibrated and periodically checked with an electric fan psychrometer, HTAG's proved to be our most valuable single tool for planning and timing experimental fires.

It was often desirable to ignite our fires to coincide with evening moderation of windspeed and rising relative humidity. Consistent daily patterns of wind, relative humidity, and temperature appeared within each general weather system. Favorable ignition conditions could be identified on HTAG records of days immediately preceding the proposed burn day. For example, if the preceding day's records showed opportunities for burning, and if the burn day's record and the spot forecast gave evidence that a similar pattern was developing, crews could then be mobilized. Costs and the number of canceled burns were thereby minimized.

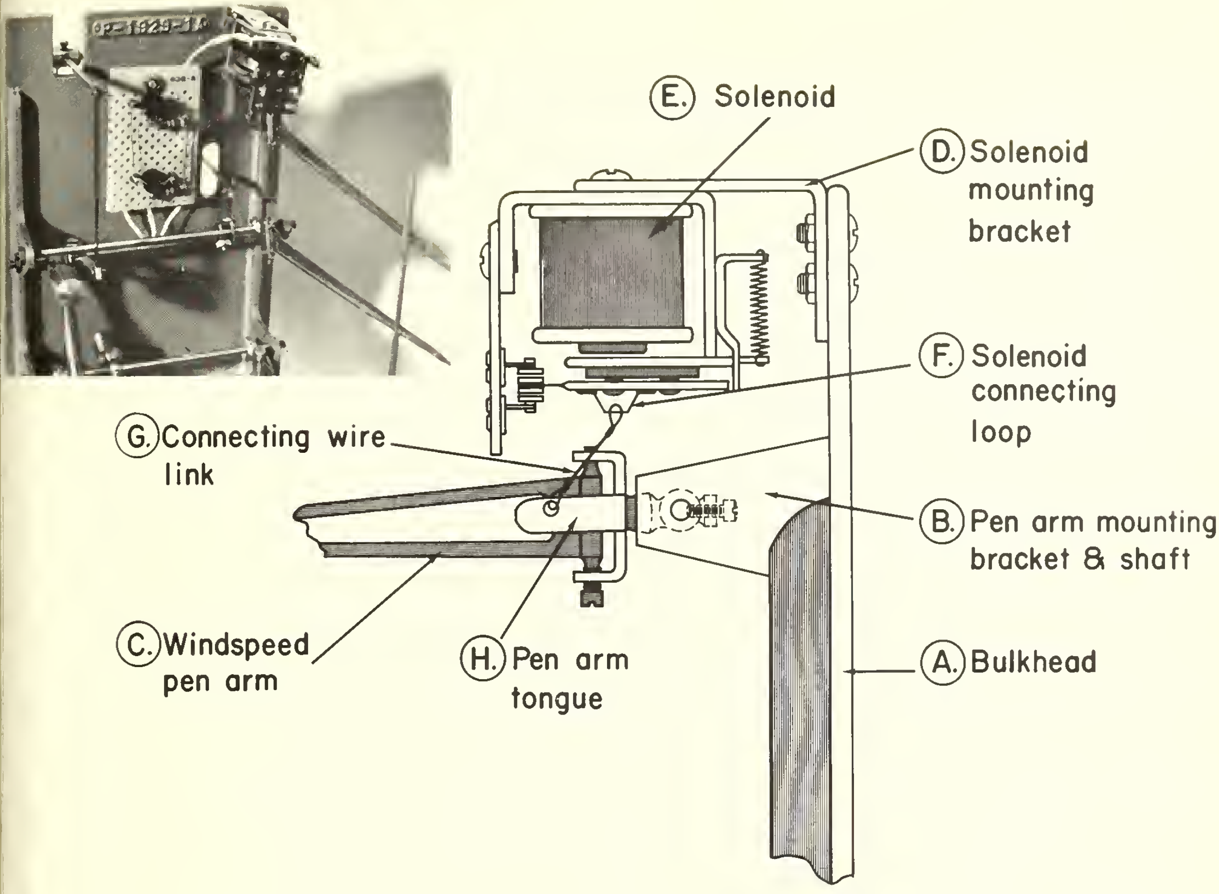


Figure 5.--Closeup view and sketch of the method of attaching solenoid and additional pen arm on a hygrothermograph bulkhead.

Other Applications

The success of the HTAG in providing continuous onsite records of windspeed, temperature, and relative humidity for prescribed fire operations suggests other applications of use to fire managers.

The HTAG can provide continuous weather data at the site of large wildfires to help fire behavior officers and fire-weather meteorologists relate existing synoptic conditions to possible fire behavior. In addition, the weather conditions existing at times of erratic fire behavior or rapid fire spread can be easily identified on the HTAG chart for postfire critiques.

The HTAG has several fire-danger rating applications. Foremost among them is its ability to provide a more complete record of fire danger than may be obtained from the once-daily observation of fire-weather factors. With the aid of the HTAG record, the fire manager can compare standard observation time values with maximum, minimum, and mean temperature and relative humidity trends, nighttime recovery patterns, and windspeed patterns. Hourly and diurnal variations of these weather factors are easily observed on the chart record. The importance of considering 24-hour records of this type when appraising fire danger has been cited by Barrows (1951) in his discussion of the thermal belt in the Rocky Mountains and more recently by Gwinner (1965) in his study of airmass as related to fire danger in the South.

When supplemented by precipitation records, National Fire-Danger Rating System Spread and Buildup Indices can be computed from the HTAG record. This capability is useful in maintaining fire-danger records during periods when an observer is not available.

A fire-weather climatology for a given area can be developed by means of a combination of the HTAG and recording rain gage. Such a record is valuable in fire-weather forecasting and fire control planning. With proper interpretation it can form the basis for selection of fire-danger station sites.

This discussion on the HTAG has been limited to its uses in fire management. Workers in other fields may recognize additional applications.

LITERATURE CITED

Barrows, Jack S.
1951. Fire behavior in northern Rocky Mountain forests. U.S. Forest Serv., Northern Rocky Mountain Forest and Range Exp. Sta. Pap. 29, 103 pp., illus.

Gwinner, Myron W.
1965. Forest fire danger as related to airmass in the Ouachita Mountains. U.S. Forest Serv. Res. Note SO-21, 4 pp., illus.

Hardy, Charles E., Charles E. Syverson, and John H. Dieterich.
1955. Fire-weather and fire-danger station handbook. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta. Misc. Pub. 3, 84 pp., illus.

Hayes, G. L.
1942. A discussion of hygrographs. U.S. Forest Serv., Northern Rocky Mountain Forest and Range Exp. Sta. Res. Note 25, 6 pp., illus.

Hofman, J. V., and William B. Osborne, Jr.
1923. Relative humidity and forest fires. U.S. Forest Serv., 22 pp., illus.

MacHattie, L. B.
1958. Accuracy of the hair hygrograph. Can. Dep. Transp., Circ. 3022, TEC 265, 11 pp., illus.

Reigner, Irvin C.
1964. How to make a wind-movement recorder from any spare drum-type recorder. U.S. Forest Serv. Res. Note NE-21, 4 pp., illus.

U.S.D.A. Forest Service.
1964. National fire-danger rating handbook. U.S.D.A. Forest Serv., Category 2 Handbook 5123.3.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-88

1969

AN INSTANCE OF LIGHTNING DAMAGE AND INFESTATION OF PONDEROSA PINES BY THE PINE ENGRAVER BEETLE IN MONTANA

Richard F. Schmitz and Alan R. Taylor[1]

ABSTRACT

Lightning damage to a struck ponderosa pine (Pinus ponderosa Laws.), the pattern of infestation in its bole by the pine engraver beetle Ips pini (Say) (Coleoptera: Scolytidae), and the success of the pine engraver infestation of surrounding sapling- and pole-size trees were documented in a western Montana study. The struck tree became infested for its entire length by bark beetles. Seventy-six percent of the immature trees within 80 feet of the struck tree also became infested. Attacks tended to be more successful closer to the struck tree and in trees in relatively moist soil. The possibility exists that the discharge that struck the mature tree may have caused undetected damage to surrounding trees and disposed them to successful attack by the bark beetles.

The pine engraver beetle Ips pini (Say) (Coleoptera: Scolytidae) is an important pest of standing ponderosa pines (Pinus ponderosa Laws.) of sapling and pole size in the northern Rocky Mountains. Most tree killing occurs during hot, dry summers when oleoresin exudation pressure is reduced and the likelihood of successful beetle attack is increased (Vité 1961). Tree killing by this insect fluctuates greatly from year to year. Hundreds of thousands of trees, often in groups of more than a thousand,[2] may be killed during outbreaks.

During years of limited pine engraver activity, the beetle confines its attacks to slash, tops of mature trees, and small groups of standing sapling- and pole-size trees that often have been damaged by fire or broken off by wind or snow. Observers have long been aware that lightning-struck trees may also trigger infestations (Hopkins

---

[1]Respectively, Research Entomologist, in Moscow, Idaho, at Forestry Sciences Laboratory, maintained in cooperation with the University of Idaho, and Research Forester, Northern Forest Fire Laboratory, Missoula, Montana.

[2]Terrell, Tom T. 1964. Oregon pine Ips generations in the Northern Region 1962-1963. Unpub. rep., U.S.D.A. Forest Serv., Northern Region, Missoula, Montana.

Figure 1.--Aerial view of group kill. Light-colored tree (arrow) is the lightning-struck, mature pine surrounded by dead saplings and poles.

1909; Thatcher 1960; McMullen and Atkins 1962), but little has been published about the nature of lightning damage to the struck tree, the pattern of infestation on the bole, and the extent of the beetle attack in surrounding trees as reported here.

On September 12, 1966, we located a mature, lightning-struck ponderosa pine surrounded by a group of dead immature (sapling- and pole-size) ponderosa pines that were infested by the pine engraver (fig. 1). This group of trees was on a narrow ridge oriented NNE-SSW at 5,000 ft. elevation about 6 miles southwest of Missoula, Montana. The drier southeast-facing side of the ridge contained an open stand of ponderosa pine and Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco). The more moist northwest slope supported a denser stand of Douglas-fir and western larch (Larix occidentalis Nutt.). The prevailing wind is from the southwest.

LIGHTNING EFFECTS

The struck pine was 79 ft. tall and 24 in. diameter at breast height. The lightning scar on this tree (fig. 2) was typical of those on conifers throughout the northern Rocky Mountains (Taylor 1965). The spiral scar extended from 13 ft. below the tree's tip to the ground. It increased in width from 5 in. at its top to 17 in. at the ground. Except for a few narrow slivers of outermost sapwood, only bark was removed by the discharge from its path along the bole. No fire resulted.

Figure 2.--Mature pine with lightning scar (arrows) and some of the surrounding trees attacked by the pine engraver.

A less commonly observed characteristic of the lightning damage was an excavation in the soil at the base of the lightning scar. Soil loosened but not ejected by the lightning was carefully removed by hand, revealing the 4- by 1- by 1-ft. excavation shown in figure 3. Several lateral roots were severed. The lightning also damaged a Douglas-fir sapling 17 ft. northeast of the struck pine, rupturing its bark and excavating some soil at its base.

The date of the lightning discharge is unknown. However, it was estimated to be about July 10, 1966, from the date of discovery, stage of beetle brood development, differentiation of the current annual ring, and radar records of thunderstorms in the area.

BEETLE INFESTATION

The age and vigor of the struck tree, as determined by the Ponderosa Pine Tree Classification (Keen 1943) was 3B (mature tree, crown vigor fair to poor) and was risk class 2 (moderate risk of beetle attack) as defined by Salman and Bongberg (1942). The upper two-thirds of the struck pine was infested by the pine engraver except for a small area of mountain pine beetle (Dendroctonus ponderosae Hopk.) at 50 ft. The lower 20 ft. of the bole was infested primarily by the western pine beetle (Dendroctonus brevicomis Lec.) but also showed evidence of attack by the pine engraver. Lack of

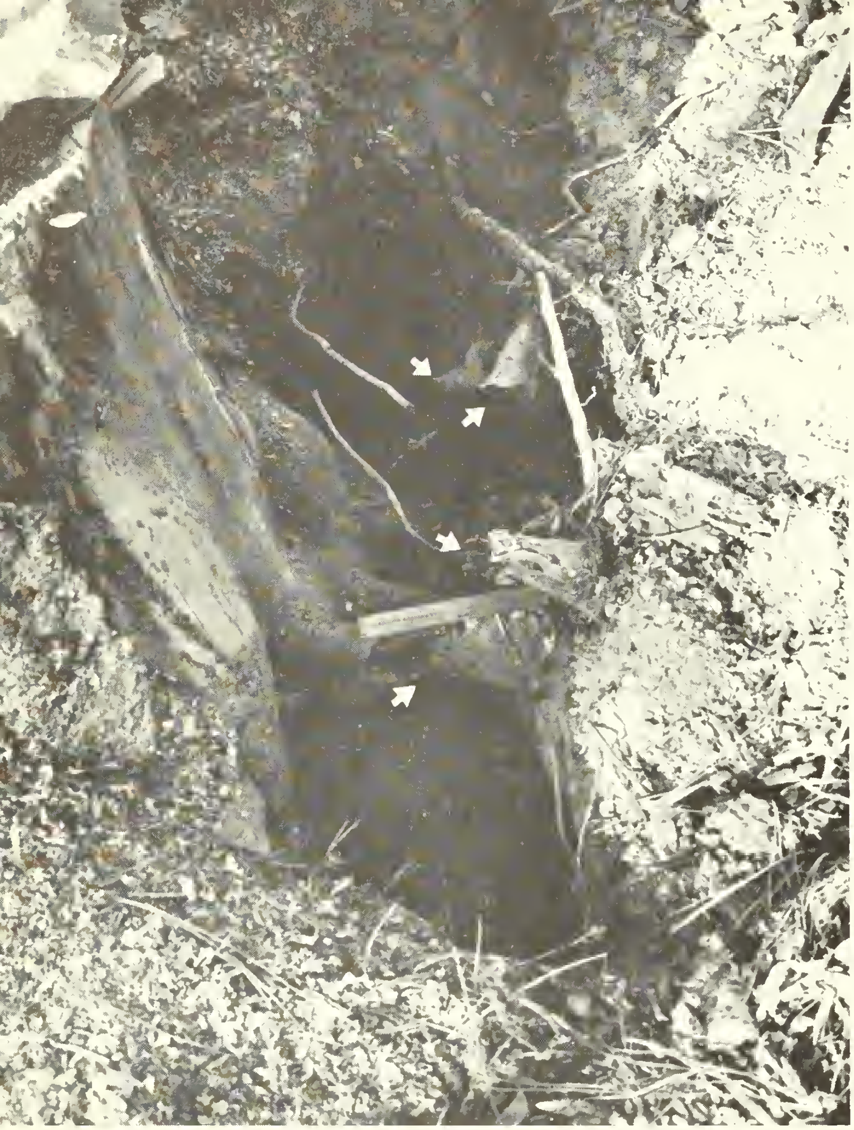


Figure 3.--Soil excavation at base of struck ponderosa pine, showing severed lateral roots (arrows). Rule is 6 in. long.

pitch tubes, abundance of emergence holes, and condition of galleries in the inner bark indicated a high rate of survival of the pine engraver. While most of the pine engraver broods had emerged from the tree at time of examination, a few callow adults and some associated insects were still present.

The extent and degree of infestation are evident from figure 4, which shows the positions of all trees 1.0 in. d.b.h. and greater, growing within an 80-ft. radius of the lightning-struck pine. No attacked trees were found beyond the 80-ft. radius. The 96 immature ponderosa pines within the 80-ft. radius were examined for presence and success of attack by the pine engraver beetle, and classified on the following basis: Successfully attacked trees showed evidence of larval development in the phloem, while unsuccessfully attacked trees lacked larval mines, though they may have contained egg galleries; unattacked trees had no sign of bark beetle entry. Results of the classification are shown in table 1 and figure 4.

Figure 4.--Map showing all trees 1.0 in. d.b.h. and greater within 80 ft. of mature, lightning-damaged ponderosa pine.

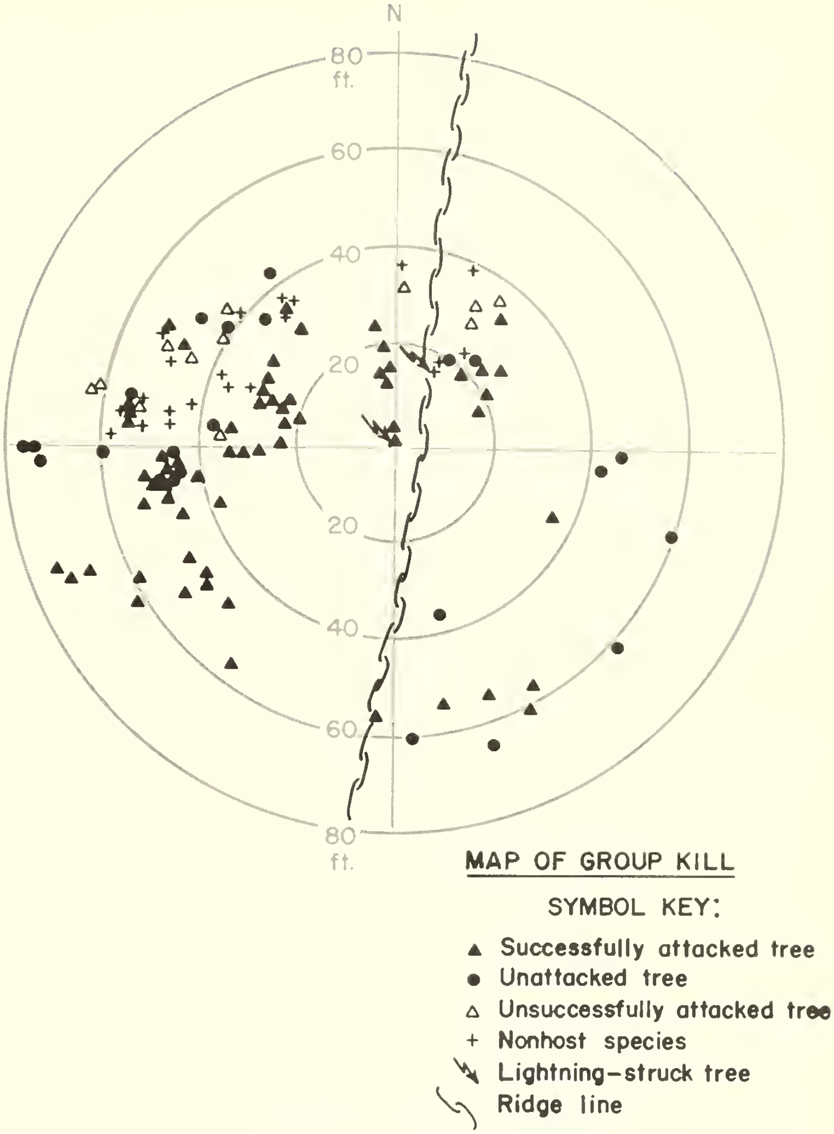


Table 1.--Rate and success of attack by the pine engraver in 96 immature ponderosa pines in relation to distance from a mature, lightning-struck pine

Distance from struck pine (feet)	Total trees	Trees attacked	Attacks successful	Percent of total trees attacked	Percent of attacks successful
0-20	9	8	8	89	100
21-40	31	27	22	87	81
41-60	42	31	26	74	84
61-80	14	7	5	50	71
Total	96	73	61	76	84

Some differences with regard to aspect were evident. The pine engraver beetle successfully attacked 18 percent more of the pine trees growing on the moist northwest-facing slope than on the drier southeast-facing slope:

	NW	SE
Total number trees	72	24
Percent attacked	80	62
Successfully	68	50
Unsuccessfully	12	12

Forty-three percent of the successfully attacked trees on the moist slope showed resistance to beetle attack in the form of pitch tubes, compared with 52 percent of those successfully attacked on the dry slope.

DISCUSSION

We lack positive knowledge of the dates of lightning damage and initial attack by bark beetles in the mature tree and the immature trees surrounding it. However, the evidence leaves little doubt that the bark beetles followed the lightning damage. This sequence of events fits that reported by Dixon and Osgood (1961), Johnson (1966), and Anderson and Anderson (1968), who cite the attractiveness of lightning-damaged pines to bark beetles.

A more interesting question is whether the attacks in the surrounding immature trees resulted from their being disposed by unseen lightning damage to their roots (Komarek 1964), or whether they were attacked after and as a result of a mass attraction created by successful infestation of the larger tree (Miller and Keen 1960; McMullen and Atkins 1962). Quite possibly, both of these mechanisms were involved. However, reports of group tree mortality around lightning-struck trees in the apparent absence of insect activity (Stevens 1918; Shipley 1946; Murray 1958; Minko 1966) reinforce the hypothesis that the trees surrounding the struck tree suffered lightning damage to their roots.

The conditions described here suggest three questions:

1. Infestation by the pine engraver of the entire stem contrasts with the infestation pattern reported by Johnson (1967) for ponderosa pines not struck by lightning. Is this difference typical?
2. Rate of successful attack diminished with distance from the lightning-struck tree. Is it likely that lightning damaged the roots of the nearby trees, lowering oleoresin exudation pressure and thereby disposing the trees to successful attack?
3. A slightly higher rate of successful attack occurred on the more moist side of the ridge, where it might be expected to be lower, owing to higher resistance of trees to beetle attack. Did lightning lessen such resistance?

Only further study can supply answers to these questions. Such study would require prompt detection of lightning damage so that subsequent events could be properly documented. Equally important, actual physical damage or physiological change prior to attack would need to be demonstrated in trees surrounding each struck tree.

LITERATURE CITED

Anderson, N. H., and D. B. Anderson.
1968. Ips bark beetle attacks and brood development on a lightning-struck pine in relation to its physiological decline. Florida Entomol. 51(1):23-30.

Dixon, John C., and E. A. Osgood.
1961. Southern pine beetle: a review of present knowledge. U.S. Forest Serv., Southeastern Forest Exp. Sta., Sta. Pap. 128, 34 pp.

Hopkins, A. D.
1909. Practical information on the scolytid beetles of North American forests. Part I. Bark beetles of the genus *Dendroctonus*. U.S. Bur. Entomol. Bull. 83, 169 pp.

Johnson, Philip C.
1966. Attractiveness of lightning-struck ponderosa pine trees to *Dendroctonus brevicomis* (Coleoptera: Scolytidae). Ann. Entomol. Soc. Amer. 59(3):615.

______ 1967. Distribution of bark beetle attacks on ponderosa pine trees in Montana. U.S. Forest Serv. Res. Note INT-62, 7 pp.

Keen, F. P.
1943. Ponderosa pine tree classes redefined. J. Forest. 41(4):249-253.

Komarek, E. V., Sr.
1964. The natural history of lightning. Third Annu. Tall Timbers Fire Ecol. Conf. Proc. 1964:139-186.

McMullen, L. H., and M. D. Atkins.
1962. On the flight and host selection of the Douglas-fir beetle *Dendroctonus pseudotsugae* Hopk. (Coleoptera: Scolytidae). Can. Entomol. 94(12):1309-1325.

Miller, J. M., and F. P. Keen.
1960. Biology and control of the western pine beetle. U.S. Forest Serv. Misc. Pub. 800, 381 pp.

Minko, G.
1966. Lightning in *Radiata* pine stands in northeastern Victoria. Australian Forest. 30(4):257-267.

Murray, J. S.
1958. Lightning damage to trees. Scot. Forest. 12(2):70-71.

Salman, K. A., and J. W. Bongberg.
1942. Logging high risk trees to control insects in pine stands of northeastern California. J. Forest. 40(7):533-539.

Shipley, J. F.
1946. Lightning and trees. Weather 1(7):206-210.

Stevens, H. E.
1918. Lightning injury to citrus trees in Florida. Phytopathology 8(6):283-285.

Taylor, Alan R.
1965. Diameter of lightning as indicated by tree scars. J. Geophys. Res. 70(22):5693-5695.

Thatcher, Robert C.
1960. Bark beetles affecting southern pines: A review of current knowledge. U.S. Forest Serv. Southern Forest Exp. Sta. Occas. Pap. 180, 25 pp.

Vité, J. P.
1961. The influence of water supply on oleoresin exudation pressure and resistance to bark beetle attack in Pinus ponderosa. Boyce Thompson Inst. Contrib. 21(2):37-66.

ACKNOWLEDGMENTS

The assistance of Philip C. Johnson, Principal Entomologist, and John E. Bruns, Aerial Lightning Observer, is gratefully acknowledged.

Research Note

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

USDA Forest Service
Research Note INT-89 1969

ASPEN SPROUT PRODUCTION AND WATER USE

Robert S. Johnston[1]

ABSTRACT

Sprouting response and soil moisture depletion on aspen plots were compared under four experimental conditions: (a) clearcut, (b) clearcut, stumps sprayed with sodium arsenite, (c) basal injection of sodium arsenite, and (d) control. Numbers of sprouts varied with treatment for 2 years, but after 4 years the numbers of sprouts on all plots were about equal. Clearcutting the aspen reduced soil moisture depletion by 3 to 4 inches in a 6-foot soil profile during each of three growing seasons.

The objectives of managing aspen (Populus tremuloides Michx.) in the Intermountain region can be quite diverse, including regeneration of commercial stands, revitalization of degenerate stands and, in some instances, stand manipulation to increase water yield. Regardless of the objectives, management can be successful only if both the treatment effects and their duration can be predicted. This study was begun to increase confidence in predictions of this type; more specifically, to test the effects of several management treatments on aspen sprout production, and also to evaluate the changes in soil moisture depletion following aspen removal.

STUDY AREA AND METHODS

Plots were established in a single aspen clone near the headwaters of Farmington Creek, Davis County Experimental Watershed, in Utah. The site is at 7,800 feet elevation on a northwest-facing 15-percent slope. At the time of the study, the clone had a two-storied aspen canopy (fig. 1) with average heights of 48 and 17 feet for the dominant and codominant trees, respectively. Basal area was 90 sq.ft./acre. The diameter (d.b.h.) of all trees on the control plots was measured. Only four were more than 10 inches d.b.h., 20 fell in the 5- to 10-inch d.b.h. class, and the remaining 97 averaged 2.4 inches d.b.h. A sampling of eight trees showed that diameter was a good indicator of age, with stem ages varying from 29 years for a tree 2 inches d.b.h. to 88 years for a tree 12 inches d.b.h.

---

[1]Associate Forest Hydrologist, stationed in Logan, Utah, at the Forestry Sciences Laboratory, maintained in cooperation with Utah State University. The author acknowledges the work of John D. Schultz, Assistant Professor of Forest Science, Utah State University, who planned the study and completed the preliminary treatments while he was a Research Forester with the Intermountain Station.

Figure 1.--A portion of the study area showing the aspen sprouts on some of the treated plots in the foreground and undisturbed double-canopied aspen clone in the background. A recording rain gage is in the center of the cleared plots.

Soils on the study area are deep, well drained, and colluvial. They vary with depth from a sandy loam to a very gravelly clay loam. Parent materials are sandstone, gneiss, and schist.

In an area measuring 100 by 150 feet, nine adjacent plots were established in the clone in a three-by-three pattern. Three additional plots were designated as controls at the lower end of the area. Each plot was divided into 16 subplots of 1 milacre each. To isolate the root systems, a trench 2 feet wide and 3 feet deep was dug around each plot, lined with roofing paper, and refilled. An 8-foot fence enclosed the entire study area, thereby excluding deer and stray sheep.

Three treatments, each with three replications, were completed on the nine plots in the summer of 1963. Treatments included (a) clearcut, (b) clearcut with all stumps sprayed with sodium arsenite, and (c) basal injection of all stems with sodium arsenite using the "Little Tree Injector."[2]

Aspen sprouts were counted on each plot early in the growing season and again in the fall, from 1964 through 1967. In addition, a complete survey of vegetation in 1966 quantified the heavy ground cover of vegetation and litter on both the treated and control plots (table 1). The percentage composition by species is presented in table 2.

Table 1.--Ground cover on control and treated plots

Type	Control plots	Treated plots
	- - - - - - Percent	- - - - - - -
Vegetation	67	75
Litter	27	18
Bare soil	6	7

[2]Use of trade names herein is for identification only and does not imply endorsement by the USDA Forest Service.

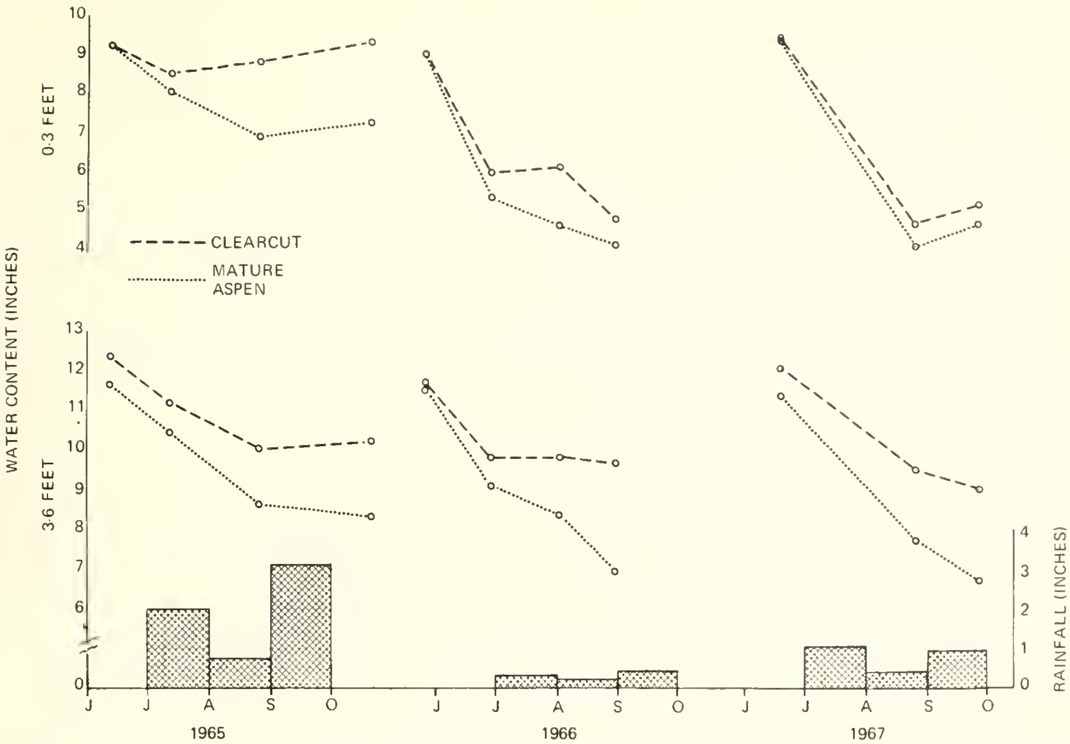


Figure 3.--Moisture content in the 0- to 3-foot and 3- to 6-foot soil profiles.

The soil moisture measurements are separated for the upper and the lower 3 feet of the profile and presented in figure 3. Each year, at both depth ranges, there was less soil moisture depletion in the clearcut plots than in the control plots. The greatest reduction in water loss from the surface 3 feet occurred in 1965, the second year after treatment. The reduction declined substantially in succeeding years. Clearcutting reduced soil moisture loss in the 3- to 6-foot portion of the soil profile by an average of 2.3 inches per year. Water content was much more consistent in this lower portion of the profile than in the surface soils.

Summer precipitation has the greatest influence on moisture content in the surface few feet of soil. In both 1965 and 1967, soil moisture increased at the end of the season in response to late season rain. Summer rainfall in 1965 was above average and is reflected by the high water content in the soils throughout the season.

DISCUSSION

Although the experimental design did not allow the detection of a statistically significant difference in the number of sprouts at any time after treatment, it is apparent that within the limits of this clone the various treatments do affect the number of sprouts, at least during the few years immediately following treatment. The general decline in number of sprouts may be attributed to competition between sprouts and with other species. The results indicate that aspen regeneration is neither improved nor retarded beyond the first few years by the treatments used in this study.

Figure 2.--Aspen sprout numbers, 1964-1967, following three treatments to the parent stand in 1963. Sprout numbers are an average of three plots.

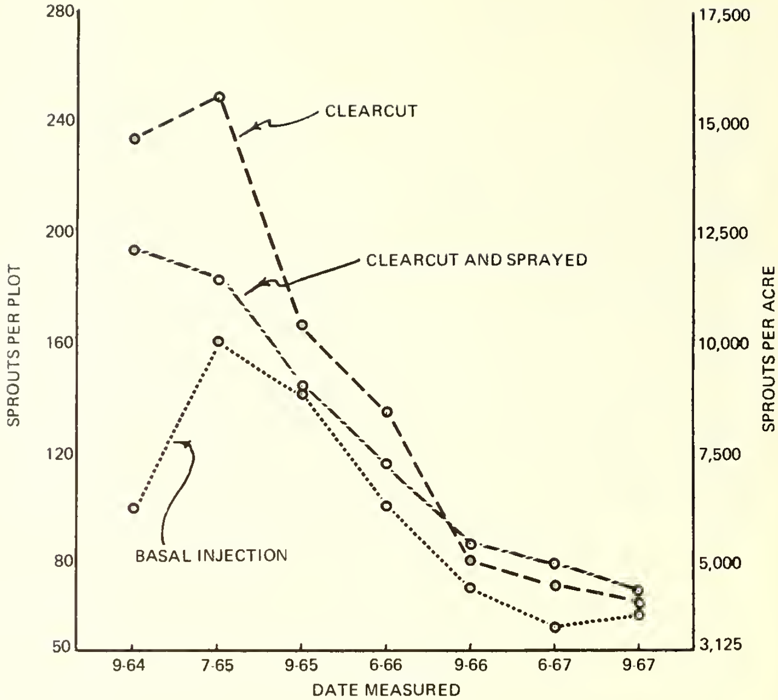


Table 3.--Soil moisture depletion and evapotranspiration in control and clearcut plots, 1965-1967

Item	1965		1966		1967	
	Control	Clearcut	Control	Clearcut	Control	Clearcut
	- - - - - - - - - - - - - - - - - - Inches - - - - - - - - - - - - - - - - - -					
Initial moisture content[1]	20.92	21.63	20.72	20.61	21.52	21.55
Final moisture content	15.67	19.60	11.21	14.65	10.86	13.91
Soil moisture depletion	5.25	2.03	9.51	5.96	10.66	7.64
Growing season precipitation	5.87	5.87	1.01	1.01	2.47	2.47
Evapotranspiration	11.12	7.90	10.52	6.97	13.13	10.11
Evapotranspiration difference	3.22		3.55		3.02	

[1]Each soil moisture measurement is the average water content for a 6-foot depth calculated from two access holes on each of three plots.

Table 2.--Vegetative composition on control and treated plots

Species	Control plots	Treated plots
	Percent	
Populus tremuloides[1]	6	16
Symphoricarpos spp.	43	10
Bromus carinatus Hook. & Arn.	16	18
Hackelia floribunda (Lehm.) I. M. Johnston	1	8
Senecio serra Hook.	2	6
Valeriana occidentalis Heller	2	12
Remaining species	30	30

[1]Stems less than 6 feet tall.

Two soil moisture access tubes were installed on each of the control and clearcut plots. With a neutron probe, soil moisture measurements were made to a depth of 6 feet at least three times during each of the 1965, 1966, and 1967 growing seasons.

RESULTS

ASPEN SPROUTING

The effects of the three treatments on aspen sprouting are shown in figure 2. Although a considerable difference in sprout numbers is apparent during the first 2 years after treatment, the difference rapidly diminishes thereafter. A general decline in the numbers of sprouts occurred each year between the beginning and end of each growing season. During the 4 years following treatment, the basal injection of sodium arsenite consistently produced the lowest number of sprouts. However, there was no statistically significant difference in sprout numbers among treatments at any time, because the experimental design was not sensitive enough to reveal it. Sprout numbers frequently ranged from 0 to more than 30 stems (0 to 30,000/acre) on the milacre subplots; but when calculated on a whole plot basis, the numbers of sprouts never exceeded 21,000 stems per acre.

SOIL MOISTURE DEPLETION

Clearcutting the aspen noticeably affected soil moisture depletion (table 3). The initial measurements were very similar in each of the 3 years. The difference between initial and final measurements each year clearly indicates 3 to 4 inches less soil moisture consumption on the clearcut plots. Rainfall totaled 5.87 inches from July to October 1965, more than four times the amount for the same period in 1966. It is assumed that both surface runoff and deep percolation losses were insignificant during the growing season; therefore, summer precipitation is added to the soil moisture depletion to estimate evapotranspiration losses (table 3). Evapotranspiration losses averaged 3.26 inches less from the clearcut than from the control plots.

The clonal growth habit of aspen is responsible for considerable genetic variability among aspen stands. This variation is manifested in the ability of a given stand to produce suckers.[3] [4] Study of numerous other clones is required before treatment results such as those of the present study can be confidently extrapolated over large areas.

This study contributes to the large number of observations concerning the water savings that can be realized by removing deeply rooted vegetation. Here 3 to 4 inches of soil moisture were "saved" each year in the 6-foot profiles of the clearcut plots. Although the treatment effect was reduced as time passed, 4 years after treatment the reduction in soil moisture depletion was still 3 inches. The reduction in water consumption occurred mostly in the lower 3 feet of the profile. We can expect the total reduction in water loss to be greater than the measured 3 to 4 inches if the water loss measured on the control plots from the 6-foot depth to a depth of maximum root penetration is included. The maximum rooting depth of aspen often extends to 9 or 10 feet, but varies greatly with soil type and depth.[5]

The three control plots could have been more appropriately located throughout the study area, rather than all placed below the clearcut plots. However, the difference in position on the slope between the two treatments probably has not greatly affected the conclusions regarding water consumption. The maximum distance between soil moisture access holes on the clearcut and control plots is less than 150 feet and the slope is moderate. Differences in soil moisture attributable to slope position would, if anything, have produced a conservative measurement of soil moisture use between treatments.

A minimum of 3 to 4 inches of water to a depth of 6 feet can be "saved" on some sites by removing aspen. Theoretically, the water saved becomes available for a higher priority use at some future time and place. This saving can be expected for several years after treatment.

---

[3]Barnes, B. V. The clonal growth habits of American aspen. Ecology 47(3):439-447. 1966.

[4]Garrett, P. W., and R. Zahner. Clonal variation in suckering of aspen obscures effect of various clearcutting treatments. J. Forest. 62(1):749-750. 1964.

[5]Gifford, G. F. Aspen root studies on three sites in northern Utah. Amer. Midland Natur. 75(1):132-141. 1966.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-90

1969

TREE-BOLE IGNITION IN SUPERIMPOSED LIGHTNING SCARS [1]

Alan R. Taylor, Research Forester [2]

ABSTRACT

This Note presents observations on a little-known mode of tree-bole ignition by lightning in which a fire-setting discharge partially superimposes its furrow upon an older lightning scar and causes ignition in the older injury.

Lightning strikes thousands of trees around the world every day. In most instances a discharge does not cause fire but inflicts structural damage on the struck tree. The extent of damage ranges from no obvious injury at all to virtual destruction of the tree. [3] In conifers, the most common damage effect is a shallow furrow 2 to 10 inches wide that spirals along the trunk, exposing only the outermost layers of sapwood in its path. [4]

SUPERIMPOSED LIGHTNING FURROWS

Occasionally lightning strikes the same tree more than once during the tree's lifetime. When this happens, the later discharge sometimes follows essentially the same path taken by a previous discharge along the tree bole. Thus, one furrow is partially superimposed upon the other. I have seen evidence of this on 11 live conifer trees in western Montana. Three of the lightning events resulted in fire. In all three instances the evidence suggests that ignition occurred in superimposed-furrow regions on the boles. This Note briefly describes these three events and places emphasis upon the most recent one, for which both the fire-setting discharge and its effects were documented.

---

[1] Most of the information presented in this Note was published in: Taylor, Alan R. Superimposed lightning scars and tree-bole ignition by lightning. Fire Control Notes 30(1): 9-10, Winter 1969.

[2] Stationed at Northern Forest Fire Laboratory, Missoula, Montana 59801.

[3] Taylor, Alan R. Lightning damage to forest trees in Montana. Weatherwise 17(2): 61-65. 1964.

[4] Murray, J. S. Lightning damage to trees. Scottish Forest. 12(2):70-71. 1958. Also: Taylor, Alan R. Diameter of lightning as indicated by tree scars. J. Geophys. Res. 70(22):5693-95. 1965.

THREE INSTANCES

My first experience with this phenomenon occurred on June 30, 1962. On the previous day lightning had struck and ignited a small (40 ft. tall, 12 in. d.b.h.) ponderosa pine (Pinus ponderosa Laws.) near Missoula, Montana. On the middle 20 feet of this tree was a shallow, spiral lightning scar several years old, partially closed and containing exuded resin. Superimposed on the lower end of this scar, which terminated about 12 feet above ground, was a new lightning furrow. Evidence at the scene and an interview with the smokechaser clearly indicated that the more recent discharge ignited the resin-covered fuel in the lower section of the older scar. A burning wood sliver, 3 feet long, was ejected from the old wound and stuck in the ground some 13 feet from the burning tree.

The second event occurred on July 15, 1963, when lightning struck and fired a large (96 ft. tall, 35 in. d.b.h.), live, open-grown ponderosa pine, also near Missoula, Montana. The tree had been struck 7 years previously and showed a straight, shallow, partially closed scar from 37 feet to about 85 feet above ground. The new furrow, with many protruding slivers, was superimposed on the old scar for a distance of only 1 foot at the 38-foot level. Ignition occurred only in this 1-foot zone of superimposition. Exuded resin had collected at the base of the old scar and was evidently ignited by the most recent discharge.

The third ignited tree was a large (120 ft. tall, 40 in. d.b.h.) western larch (Larix occidentalis Nutt.), growing in a cutover stand of larch, Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco), and ponderosa pine in the Lolo National Forest of western Montana. Growth-ring count indicated the tree had been struck 6 years previous to the fire-setting discharge. The tree had lost its top many years earlier, and an upper branch had become the terminal leader.

The fire-setting discharge occurred at 1316:02 m.s.t. on September 14, 1966. Its electrical properties were recorded electronically at a station 16 miles from the tree, and the visible flash and subsequent fire were documented by an airborne lightning observer.[5] The methods and equipment used in the lightning recording system, and the characteristics of the discharge that caused this fire are described elsewhere by Fuquay et al.[6]

The burning tree is shown in figure 1, photographed by the observer about a minute after the discharge occurred. The new damage was superimposed on the old scar for about 60 percent of the old scar's length. Portions of the new and old damage appear in figure 2, which shows a section about 50 feet below the tree's tip and 1 foot above the highest fire damage. Note the ridges of 6 years' callus tissue and the weathered, exposed sapwood on the edge of the old furrow (lower edge in photo). Compare this with the opposite edge, where the callus tissue was removed and a thin strip of sapwood loosened by the fire-setting discharge. This appearance is typical of the other 10 trees on which superimposition of scars was observed. Note also that the old and new furrows appear to terminate at the right-hand side of the photograph. However, figure 3 shows that both reappear about a foot lower on the bole. Here most of the evidence of the new furrow was destroyed by fire but, as in figure 2, the callus tissue of the old wound was removed from the margin of the scar by the recent discharge.

---

[5] I acknowledge the substantial contribution of aerial lightning observer J. E. Bruns in the documentation of lightning effects described in this Note.

[6] Fuquay, D. M., R. G. Baughman, A. R. Taylor, and R. G. Hawe. Documentation of lightning discharges and resultant forest fires. U.S. Forest Serv. Res. Note INT-68, 7 pp. 1967.

The highest point of massive char, lower right in figure 3, was about 55 feet below the tip of the tree, near the base of the volunteer main stem, and coincided with the highest point at which smoke obscures the bole in figure 1 (lower arrow). This suggests that the older lightning scar at this point was a primary ignition site for the more recent discharge. The massive charring in this region precluded observations on the presence of resin exudation from the old wound. However, the old scar in figure 2 contained only small amounts of such deposits.

Figure 1 also suggests that ignition occurred at other points farther down the bole, either on the old lightning scar or in decayed heartwood of the lower trunk. Evidence from those areas was destroyed by fire and by severe breakage when the tree was felled to suppress the fire.

DISCUSSION

The three instances described in this Note show that tree-bole ignition by lightning sometimes occurs in an injury caused by a previous discharge. The evidence raises the question of whether the presence of exuded resins in an old lightning scar may increase the probability of tree-bole ignition by a later discharge. If it does, other types of injuries might similarly increase chances of bole ignition by lightning.

I would appreciate receiving additional observations of this phenomenon from fire control men in the field. Address correspondence to the author, Northern Forest Fire Laboratory, Intermountain Forest and Range Exp. Station, Drawer 7, Missoula, Montana 59801.

Figure 1.--Western larch struck and ignited by lightning, photographed about a minute after discharge. Upper arrow at treetip; lower arrow at highest level of smoke on tree bole. Section between arrows is volunteer terminal leader.

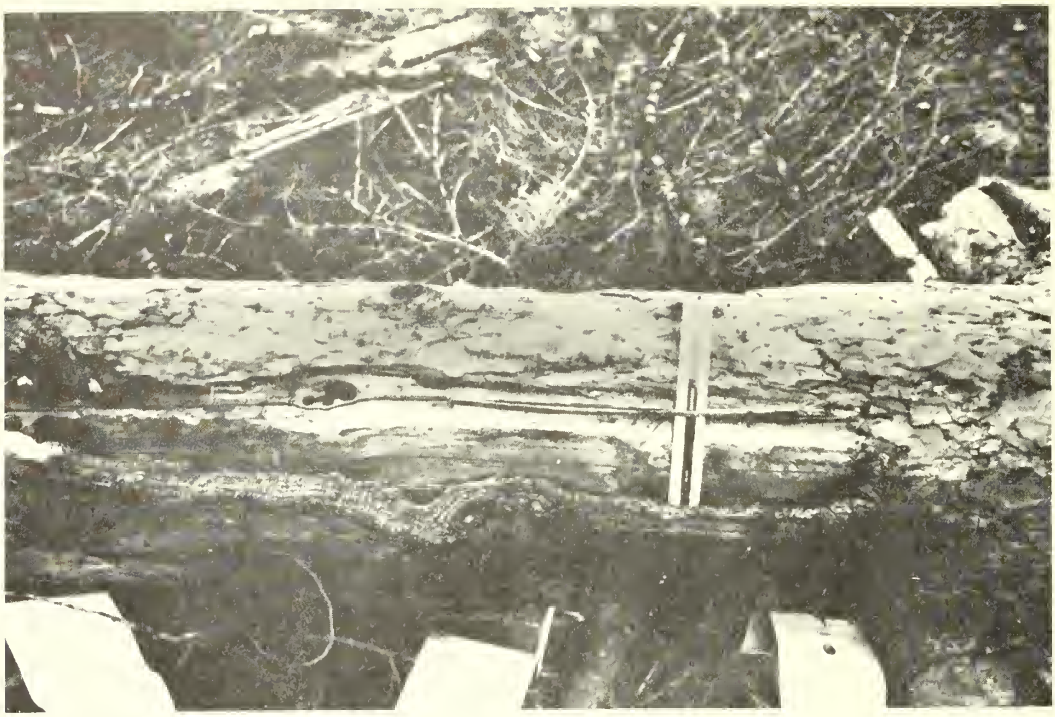


Figure 2.--New lightning damage partially superimposed on 6-year-old lightning scar. Lighter portion of furrow in upper part of photo is new damage. Callus tissue and thin sapwood strip were removed from this edge of furrow by the later, fire-setting discharge. Top of tree 50 feet to left; ruler 6 inches long.

Figure 3.--Upper extremity of fire on tree bole, 6 inches above crosscut. Massive char and wood loss on underside of bole, right, corresponds with highest level of smoke (lower arrow, fig. 1).

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

USDA Forest Service
Research Note INT-91

1969

REVISED MARSH FUNNEL TABLE FOR MEASURING VISCOSITY OF FIRE RETARDANTS

Charles W. George and Charles E. Hardy[1]

ABSTRACT

This Note publishes data on new retardants now in use.

About 3 years ago the Marsh Funnel was modified so that the viscosity of all currently used forest fire retardants could be determined in the field. The data were obtained by comparing viscosity from the Brookfield Viscometer with the flow-through time for the Marsh Funnel; thus "Marsh Funnel time" serves as an inexpensive criterion of actual viscosity.[2 3]

The revised table published here includes only products currently used. Newest of these is Phos-Chek 202 X/A.

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 Northern Forest Fire Laboratory, Intermountain Forest and Range Experiment Station, Drawer 7, Missoula, Montana 59801.

---

[1]Stationed at Northern Forest Fire Laboratory, Missoula, Montana.

[2]George, Charles W., and Charles E. Hardy. Fire retardant viscosity measured by modified Marsh Funnel. U.S. Forest Serv. Res. Note INT-41, 4 pp., illus. 1966.

[3]George, Charles W., and Charles E. Hardy. Fire retardant viscosity measured by modified Marsh Funnel. Fire Control Notes 28(4): 13-14, illus. 1967.

MARSH FUNNEL TIME--FIRE RETARDANT VISCOSITY RELATIONS[1]

Revised April 1969

Time for 1 quart to flow through funnel[2]		Fire retardant material						
		Gelgard M		Phos-Chek			Fire-Trol 100	
				202	202 X/A	259		
		Large tip[3]	Small tip[3]	Large tip	Large tip	Small tip	Large tip	Small tip
Min.	Sec.	- - - -	- - - -	- - Centipoise	- -	- -	- -	- -
0	15						930	
0	20				557		1530	
0	25				767		1900	
0	30				966	5	2140	
0	35				1155	20	2330	
0	40			540	1334	43	2480	920
0	45			680	1502	66	2590	1110
0	50			800	1659	89	2680	1250
0	55	520		900	1806	112	2750	1370
1	00	550		1000	1942	136	2800	1460
1	05	580		1080	2067	159	2840	1540
1	10	610	210	1150	2183	182	2880	1610
1	15	640	230	1210	2287	205	2900	1670
1	20	660	250	1265	2381	228	2920	1720
1	25	680	265	1320	2465	251	2930	1770
1	30	700	280	1380	2538	274	2940	1810
1	35	720	300	1420		297	2950	1840
1	40	740	315	1470		320	2960	1870
1	45	760	330	1520		343		1900
1	50	780	342	1560		367		1920
1	55	800	355	1600		390		1940
2	00	820	370	1640		413		1960
2	15	865	410	1755				
2	30	908	442	1855				
2	45	945	477	1935				
3	00	980	508	2010				
3	15	1014	537					
3	30	1045	564					
3	45	1072	591					
4	00	1098	616					
4	15	1123						
4	30	1147						
4	45	1171						
5	00	1188						
5	15	1209						
5	30	1230						
5	45	1247						
6	00	1264						

INSTRUCTIONS FOR USING THE MARSH FUNNEL

1. Place the appropriate tip in the Marsh Funnel.
2. Cover the orifice with a finger and pour a freshly agitated sample into the clean, dry upright funnel until the fluid level exactly reaches the bottom of the screen.
3. Measure the time in minutes and seconds for 1 quart of retardant to flow through the funnel (the funnel holds approximately 2 quarts).
4. 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 viscosity depends somewhat on the time since agitation and the temperature of the retardant. The viscosity found in the table will be for the retardant at the existing settling time and temperature.
2. For the samples tested, the Marsh Funnel method gave viscosities within 5 percent of the Brookfield method.
3. Numbers included within the boxes indicate the normal usage range.

---

[1] *Viscosities by Brookfield Model LVF, at 60 r.p.m., spindle 4 (except spindle 2 for Phos-Chek 259).*

[2] *Funnel must be FULL to screen before testing begins.*

[3] *Large tip diameter should be 0.269 ±.002 inch; small tip inside diameter should be 0.187 ±.002.*

Research Note

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

USDA Forest Service
Research Note INT-92 1969

THE EFFECT OF REDUCED EXTRACTIVE CONTENT ON THE BURNING RATE OF ASPEN LEAVES

C. W. Philpot[1]

ABSTRACT

Diethyl ether and acetone were used to reduce the extractive content of aspen leaves. The leaves were burned in 0.5-ft.^{2} baskets and the weight loss rate was recorded. A direct relationship between extractive content and burning rate was found. This relationship emphasizes the importance of seasonal trends in extractive content and differences between species.

The burning properties of plant fuels depend on both physical and chemical characteristics. Study of the chemical constituents of plants and their relation to flammability is necessary for evaluation of fire hazards.

A primary element in flammability is the heat content of the fuel, which varies, depending on fuel composition. Heat content, measured in B.t.u./lb., partly determines the intensity of burning, and the availability of heat content affects the rate of fire spread. Plant fuels consist mainly of carbohydrates (in the form of cellulose and other substances) and lignin; in addition, a variety of waxes, fats, oils, and terpenes, generally called ether extractives, are present in varying quantities depending on the species and the season of the year.

Past research on wildland fuels has shown that generally the extractives have the greatest heat content of any major component of the fuel (Philpot 1969). There are indications that the extractives do not undergo the complex pyrolytic changes that carbohydrates do before ignition; that is, the heat content they provide is more easily available for ignition and combustion. Some of the extractives also form a surface deposit, thus becoming even more easily available.

---

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

The specific effects of the extractives on fuel flammability are not known. To test the effect of different amounts of extractives in plant fuels on such properties as heat content, burning rate (rate of weight loss), and flame characteristics, burning studies were made using leaves of aspen (Populus tremuloides Michx.) extracted with organic solvents. Aspen leaves were used because they have a normally high extractive content, can be burned in small fuel beds, and are also being used in studies of seasonal differences in fuel characteristics. Several authors have found seasonal trends in the extractive content of leaves (Richards 1940; Philpot 1969; Short et al. 1963). Maximum content values as high as 18 percent dry weight have been reported (Dietz et al. 1962). Although we hope ultimately to find out how seasonal and species variation in extractives affects burning rate, such differences are not examined in this paper. Some differences in the extractive content of the leaves may be due to the date at which they were gathered, but no conclusions from this can be drawn.

METHODS

Whole, living aspen leaves were collected in the field once in July and once in August of 1967. After being allowed to air-dry at 72° F., the leaves from one sampling date were used for ether extraction and a matching control; those from the other date were used for acetone extraction and its control. Approximately 60 grams of leaves were extracted at once for 60 hours in a modified Soxhlet apparatus with either diethyl ether or acetone. The solvent was removed by drying in a fumehood.

Subsamples of the extracted (test sample) and nonextracted (control sample) leaves were ground to 40 mesh and analyzed for ash (mineral) content, extractive content (by ASTM procedures), and high heat content (ASTM 1956a, 1956b, 1966). Values for ash and extractives are expressed as percent dry weight. Moisture content for the above procedures was determined by Karl Fischer titration to establish the dry weight base.

Four hours before the burning tests, the leaves were spread out in the combustion chamber and allowed to reach equilibrium with controlled conditions (Anderson 1964). Moisture content at this point was not determined because there was not enough extracted sample material; the difference in moisture content between treatments was assumed to be insignificant. The dry-bulb temperature was 85° F. and the relative humidity was 22 percent. Sixty grams of leaves were placed in a circular 0.5 $ft.^2$, 1/4-inch mesh hardware cloth basket. The fuel bed was 4 inches deep. Three control and three ether-extracted fuel beds were alternately placed on a load cell and ignited with the aid of 1 ml. acetone poured directly in the center. We used this method of ignition to try to accentuate the differences in rate of spread between treatments as the fire moved out from a point source. The load cell continuously recorded weight loss over time and its rate of change per unit of time or derivative, until flaming ceased. Flame height and duration were observed and recorded. Two acetone-extracted fuel beds and three controls were burned at a later date under the same conditions.

RESULTS

The results of the chemical analyses are presented in table 1. As can be seen from the data for the controls, the leaves collected on different dates had different original extractive and ash contents. Extraction by ether and acetone affected ash content slightly or not at all. Ash contents expressed on a percent basis should increase after extraction, because of the resulting mass change. Expressing the ash contents of both the control and extracted samples on a basis that excludes the extractives reveals whether any minerals were removed by the solvents. For the ether treatment and control, the figures show the expected increase. For the acetone treatment and control, the relationship is not as close, but it still does not indicate any reduction in ash content. The heat contents of the leaves in each sample were dissimilar; these would be expected to reflect differences in the original extractive content (Philpot 1969).

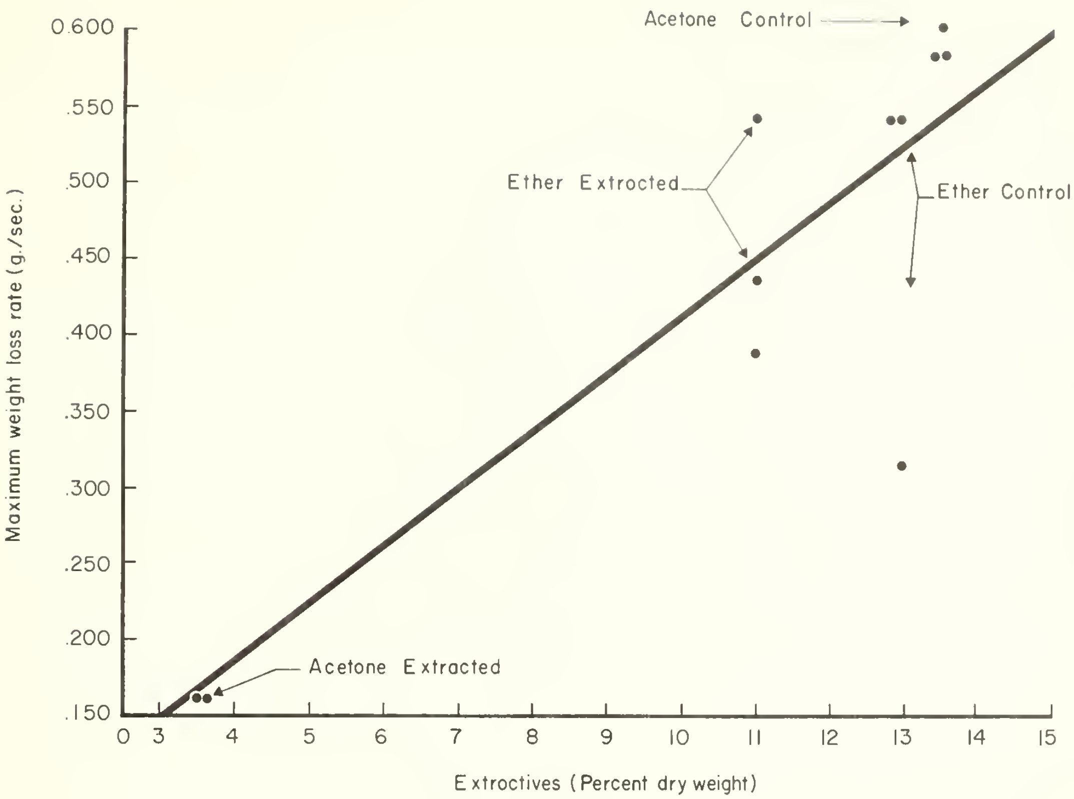


Figure 3.--The relationship between extractive content of aspen leaves and maximum weight loss rate. Each data point represents a single burning test.

$$Y = 0.0316 + 0.0377X$$

where

Y = maximum weight loss rate (grams/sec.)
X = extractive content (percent dry weight).

The coefficient of determination, r^2, is 0.76 and the level of significance is >75% but <90% as determined by the F test. The line was fitted by least squares.

CONCLUSIONS

This experiment, by no means conclusive, showed the maximum burning rate of the aspen leaves was directly proportional to their extractive content. Extraction by acetone was the most effective and reduced combustion almost to nonsustainability. Apparently, the extractives volatilize ahead of the flame front and help support combustion. The higher heat content of the nonextracted leaves, resulting from the presence of the extractives, probably accounted for some of the higher weight loss rate. Some of the reduction in burning rate of the acetone-extracted leaves and their control with respect to the ether group could be due to higher mineral content of the acetone group as a whole (Philpot 1968).

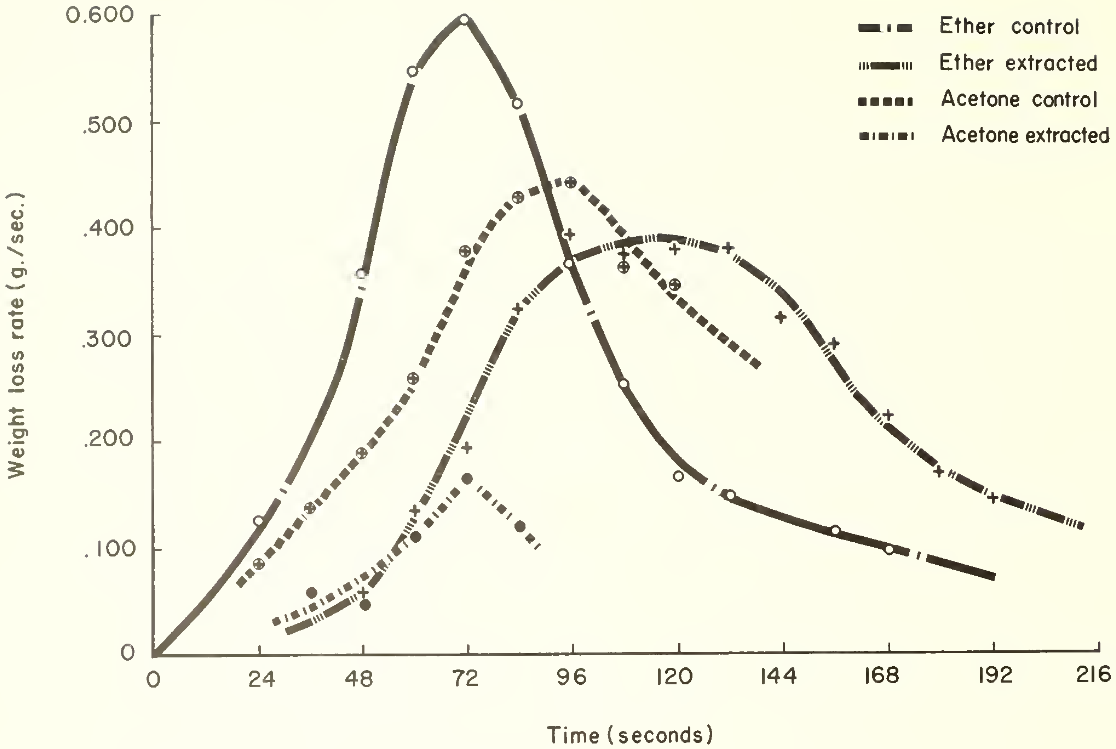


Figure 2.--Weight loss curves for natural and extracted aspen leaves. Data points are averages for the burning tests for each group.

The characteristics of the burning of the various fuel beds are tabulated below. Conditions were constant as described earlier.

	Flame height (Feet)	Maximum weight loss rate (Grams/sec.)
Ether control	2	0.59
Ether extracted	1.5	.37
Acetone control	2	.43
Acetone extracted	0.5	.15

The large variability in buildup time between the replicate fires in each treatment group made the raw data on weight loss rate extremely hard to analyze. This variability was mainly due to the method of ignition described earlier, which made buildup time dependent on the orientation and sustainability of one or two leaves at the center of the bed. In spite of this buildup variability, the shapes of the weight loss curves were found to be similar within the treatments if the time period from ignition up to active combustion was discounted. Therefore, a weight loss rate of 0.125 gram/sec. was chosen as an orientation point for the curves for all of the fires, because once this rate was achieved the combustion that was characteristic of the treatment continued. All of the replicate curves for each control and treatment were alined with this value to produce the average curves in figure 2. The maximum weight loss rate was then plotted against the extractive content (fig. 3). This relationship fits the equation:

Table 1.--Analyses of controls and solvent-treated leaves

Sample treatment	Extractive content, dry weight	Ash, dry weight	Ash, dry weight, extractive-free basis	Heat content
	- - - - - - -	Percent	- - - - - - - - - - -	B.t.u./lb.
Ether control	13.53	5.64	6.52	9,026
Ether extracted	11.03	5.72	6.43	8,615
Extractive reduction	2.50			
Acetone control	12.96	6.51	7.48	9,011
Acetone extracted	3.51	7.44	7.71	8,094
Extractive reduction	9.45			

Flame heights of the controls ranged up to 2 feet (fig. 1) and most of the fuel was consumed. A shiny band of liquid extractives could be seen on the surface of the leaves adjacent to the flame front. This liquid was not apparent when the extracted leaves were burning. Flame heights of the extracted leaves ranged only as high as 6 inches. Only about one-third to one-half of the fuel was consumed. The acetone-extracted leaves stopped flaming combustion much sooner than the ether-extracted leaves. The rate of flame spread from the ignition point was much slower for the extracted leaves.

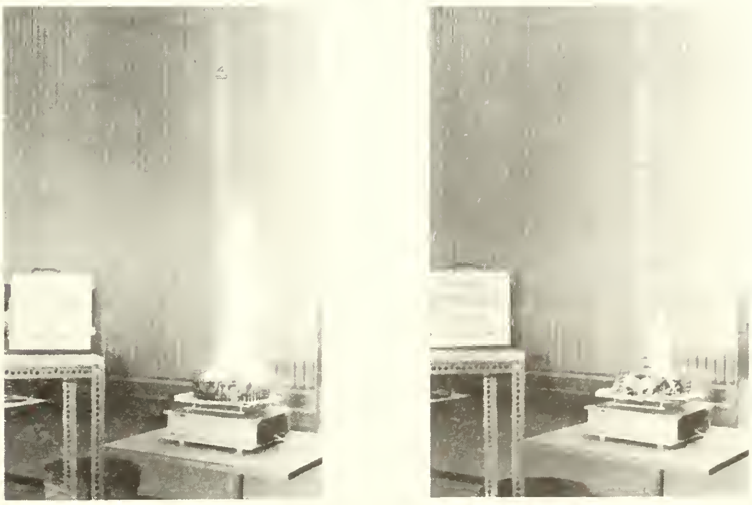


Figure 1.--Flame heights during maximum burning of control and acetone-treated aspen leaves.

Seasonal trends in extractive content, which apparently exist in many fuels, could be quite important in assessing fuel flammability. Many plants that are considered a fire hazard show an increase in extractive content during the summer months. This increase, coupled with mineral and moisture trends, may have to be considered in the evaluation of natural fuel flammability. Further experiments are now underway to test effects of change in extractive content of aspen and other fuels on burning rate, to determine the ignition characteristics of extractives, and to establish seasonal-trend prediction equations for natural fuels.

REFERENCES

American Society for Testing and Materials.
1956a. Method of ether extraction of wood. D-1108-56. Philadelphia, Pa.

______ 1956b. Method of test for ash in wood. D-1102-56.

______ 1966. Method of test for gross calorific value of solid fuel by the adiabatic bomb calorimeter. D-2015-66.

Anderson, Hal E.
1964. Mechanisms of fire spread--progress report No. 1. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Pap. 8, 20 pp., illus.

Dietz, Donald R., Robert H. Udall, and Lee E. Yeager.
1962. Chemical composition and digestibility by mule deer of selected forage species, Cache La Poudre Range, Colorado. Colo. Fish and Game Dep. Tech. Pub. 14, 88 pp.

Philpot, Charles W.
1968. Mineral content and pyrolysis of selected plant materials. U.S.D.A. Forest Serv. Res. Note INT-84, 4 pp.

Philpot, C. W.
1969. Seasonal changes in heat content and ether extractive content in chamise. USDA Forest Serv. Res. Pap. INT-61.

Richards, Leon W.
1940. Effect of chemical attributes of vegetation on forest flammability. J. Agr. Res. 60: 833-838.

Short, H. E., Donald R. Dietz, and E. E. Remmenga.
1966. Selected nutrients in mule deer browse plants. Ecology 47(2): 222-229, illus.

Research Note

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

USDA Forest Service
Research Note INT-93 1969

SEEDBED TREATMENTS INFLUENCE SEEDLING DEVELOPMENT IN WESTERN LARCH FORESTS

Wyman C. Schmidt[1]

ABSTRACT

Studies in 12- to 15-year-old western larch stands at Coram Experimental Forest in northwestern Montana show that condition of the seedbed at the time of seedling establishment strongly influences seedling development. Larch regenerates abundantly, grows rapidly, and becomes dominant where prescribed burning or mechanical scarification has reduced the amount of competing vegetation. In contrast, Douglas-fir is less sensitive to seedbed conditions for both establishment and growth. With reduced competition from larch, it subsequently dominates stands where seedbeds had little or no preparation.

Seedling and sapling stands are steadily replacing harvested old-growth western larch (Larix occidentalis Nutt.) in the northern Rocky Mountains.[2] Condition of seedbeds after harvesting is a key factor influencing initial establishment of these young stands in terms of species composition and distribution. Treatments that expose mineral soil and reduce competing vegetation favor natural regeneration of all species represented here but particularly favor western larch and Engelmann spruce. Conversely, site treatments that expose little or no mineral soil and do not destroy other vegetation discriminate against these two species and result in establishing a greater proportion of Douglas-fir and subalpine fir.

Do these initial differences expressed on various seedbeds during regeneration persist and influence the subsequent development of the new seedlings? Young stands that started on a variety of seedbeds in larch forests of northwestern Montana provided opportunity to answer this question.

---

[1]Associate Silviculturist, stationed in Missoula, Montana, at the Forestry Sciences Laboratory, which is maintained in cooperation with the University of Montana.

[2]Western larch grows in association with a wide variety of species. In this study primary associates were Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.)), Engelmann spruce (Picea engelmannii Parry), subalpine fir (Abies lasiocarpa Hook.), lodgepole pine (Pinus contorta Dougl.), and western white pine (Pinus monticola Dougl.).

STUDY AREAS AND PROCEDURES

Two stand development studies--one called Terrace Hill, the other Coram--were conducted on the Coram Experimental Forest on plots originally established to study effects of different types of seedbed on natural regeneration. Seed tree cuttings, made about 1945, were used for the original seedbed tests.[3] Seedling stands became established on all of the different seedbeds and now furnish the information used in this stand development report. Analyses here are based primarily upon data for a 5-year period in each stand--age 10 to 15 on the Terrace Hill study and age 7 to 12 on the Coram study.

TERRACE HILL

The Terrace Hill plots were on the lower half of a northeast slope and have a larch site index of 58 feet at 50 years--a medium site. Individual records were kept of all trees 1 foot and taller on 60 systematically located milacre quadrats. Initial seedbed conditions were:

Previous treatment	Initial seedbed conditions
Scarification plus removal of remaining understory	Mineral soil exposed by heavy tractor skidding; plus practically all remaining understory vegetation removed.
Scarification only	Mineral soil exposed by heavy tractor skidding; some major shrubs and residual understory trees left intact.
Removal of understory vegetation only	Litter and duff left intact; major shrubs and residual understory trees cut.
None	Litter, duff, and understory vegetation left intact.

CORAM

Plots for the Coram study were on middle north and lower south slopes. The average larch site index was 46 feet at 50 years. On the Coram study site, all trees 6 feet and taller were measured individually on 109 randomly located 4-milacre quadrats. The initial seedbed conditions were as follows:

Previous treatment	Initial seedbed conditions
Burning	Mineral soil exposed by prescribed burning; most understory vegetation killed.
Disking	Mineral soil exposed by light disking; some shrubs and grass killed.
Removal of understory vegetation only	Litter and duff left intact; major shrubs and understory trees cut.
None	Litter, duff, and understory vegetation left intact.

---

[3]These studies were planned and installed by K. N. Boe, A. L. Roe, R. C. Shearer, and A. E. Squillace.

RESULTS

The seed tree overstory and small understory trees left after logging produced enough seed during the 12- to 15-year study periods to stock all of the areas adequately--regardless of seedbed. However, there were important differences in seedling growth, species composition, and dominance on the different seedbeds.

GROWTH

Larch seedlings grew best on intensively prepared seedbeds. The more thoroughly vegetative competition was destroyed, the faster the trees on those areas grew in height. Dominant larch at Terrace Hill grew more than twice as fast on the scarified seedbeds as they did on plots that had had no seedbed treatment (table 1). The Coram study indicated the same relation--trees on plots that had been burned grew the fastest. McNamara and Reigner[4] reported similar results with Japanese larch (Larix leptolepis (Sieb. and Zucc.) Gord.). Height growth was significantly greater where seedbed preparation had been intensive.

Trees with rapid initial growth improved their relative position in the stand as they grew older. At Terrace Hill, for example, dominant larch that were 10 feet tall at age 10 grew 8 feet in the next 5 years while those that were only 5 feet tall at age 10 added only 5 feet in height during the same period.

Tree vigor can also be a good indicator of future performance. All trees at Terrace Hill, including all species and crown classes, were classified into three broad categories of vigor[5] when the study was started (fig. 1). Good vigor larch trees grew about six times faster than the poor vigor trees. Lodgepole pine, Douglas-fir, and subalpine fir showed the same relation as larch, but the characteristically slow growing spruce seedlings did not demonstrate as much growth difference between trees of different vigor classes as the other species. Good vigor spruce trees grew only twice as fast as the poor vigor trees.

Table 1.--Heights of dominant larch, 10 and 15 years old, on seedbeds at Terrace Hill

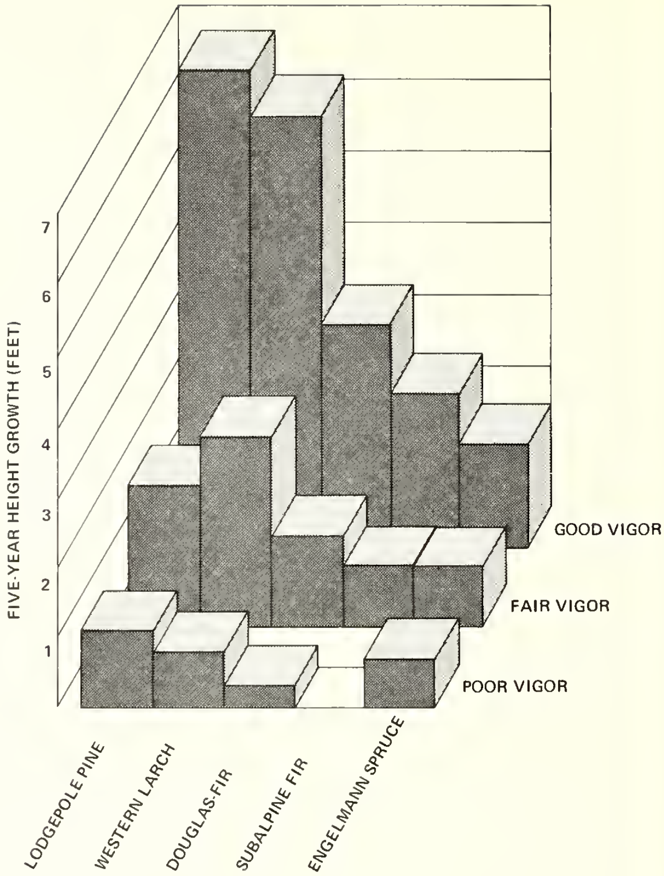
Treatment	Average height: 10 years old	Average height: 15 years old	Average 5-year height growth[1]
	Feet		
Scarification, and understory removed	4.9	10.4	5.5
Scarification only	5.1	10.9	5.8
Understory removed	4.1	8.7	4.6
None	3.2	5.5	2.3

[1]Means bracketed by a single line do not differ significantly (1% confidence level).

[4]McNamara, E. F., and I. C. Reigner. Effect of competition on height growth and survival of planted Japanese larch. U.S. Forest Serv., Northeastern Forest Exp. Sta. Forest Res. Note 103, 4 pp. 1960.

[5]The vigor classification was based upon observations of such tree characteristics as crown length and density, needle color and length, and prior growth performance.

Figure 1.--Height growth from age 10 to 15 at Terrace Hill.



Western larch and lodgepole pine grew much faster than any other species (fig. 1). A comparison of height growth of all good vigor trees showed that during the last 5 years these two pioneers grew at least twice as fast as Douglas-fir, subalpine fir, and spruce. Similar comparisons of fair and poor vigor trees showed the same general relation.

COMPOSITION AND DOMINANCE

Western larch and spruce comprised two-thirds or more of the large number of trees per acre occupying seedbeds that had been scarified on the Terrace Hill plots and broadcast burned on the Coram plots. Conversely, Douglas-fir and subalpine fir were about two-thirds of the trees stocking areas where the forest floor was largely undisturbed. The undisturbed forest floor of the untreated plots not only hindered establishment of larch and spruce seedlings, but it supported a heavy stand of shrubs and other vegetation that competed with the seedlings and reduced their growth.

Larch trees were distributed uniformly and dominated[6] the young stand on 50 percent or more of the area where mineral soil had been exposed by scarification on the Terrace Hill plots and by broadcast burning on the Coram plots (tables 2 and 3). Spruce was well distributed only where mineral soil had been exposed. Because it characteristically grows slowly in the juvenile stage, it was overtopped and dominated by its associates, particularly larch. Douglas-fir, showing little preference for any particular seedbed, was evenly distributed throughout the study area irrespective of the treatments, but it dominated more of the plots where there had been no seedbed treatment and where larch was not a strong competitor.

---

[6]The tallest tree per quadrat was considered the dominant tree.

Table 2.--Stocking and composition of dominant seedlings by seedbed conditions at Terrace Hill

Seedbed treatment	Stand age	Western larch	Douglas-fir	Other species[1]	Total	Total trees per acre (all species)
	Years			Percent		
Scarification,	10	73	13	14	100	10,470
understory removed	15	66	7	20	93	12,800
Scarification only	10	93	0	7	100	13,390
	15	93	0	7	100	17,330
Understory removed	10	47	53	0	100	3,270
	15	46	47	7	100	4,410
None	10	33	53	14	100	3,140
	15	40	40	20	100	4,210

[1]Includes Engelmann spruce, subalpine fir, and lodgepole pine.

Douglas-fir gained a comparative advantage over larch during the last 5 years on the Coram disked plots (table 3). The two species shared about an equal dominant position on these plots at age 7, but larch declined rapidly, while Douglas-fir stayed about the same. Even though disking exposed enough mineral soil to permit seedlings to become established, it did not suppress the grass and shrubs enough to give larch the competitive advantage it needed to stay in the dominant position.

DISCUSSION

The effects of different methods of site preparation on initial seedling establishment in larch forests have been well documented.[7] [8]

The results reported here demonstrate that seedbed influences the new seedling stand well beyond the initial 5-year regeneration period. Methods that favor successful establishment of young tree seedlings also favor their subsequent development. These two studies of stand development demonstrate that scarification and prescribed burning result in:

1. Greater height growth in larch; it grows nearly twice as fast on prepared sites as on untreated areas.

2. The formation of young stands composed of several species but dominated by larch.

3. Good distribution and survival of all seedlings.

[7]Roe, A. L. Larch--Douglas-fir regeneration studies in Montana. Northwest Sci. 26: 95-102. 1951.

[8]Roe, A. L. A seedbed preparation test in the larch--Douglas-fir timber type in northwestern Montana. M.S. thesis, Sch. Forest., Univ. Mont., Missoula. 1955.

Table 3.--Stocking and composition of dominant seedlings by seedbed conditions at Coram

Seedbed treatment	Stand age	Western larch	Douglas-fir	Other species[1]	Total	Total trees per acre (all species)
	Years	Percent				
Burning	7	61	19	8	88	5,117
	12	54	15	19	88	6,468
Disking	7	35	40	7	82	3,381
	12	21	38	18	77	2,803
Understory removed	7	35	21	32	88	5,669
	12	39	18	31	88	5,203
None	7	20	33	22	75	3,923
	12	14	39	19	72	3,349

[1]Includes Engelmann spruce, subalpine fir, lodgepole pine, and western white pine.

Prescribed burning and scarification not only expose enough mineral soil for good seedling establishment but, perhaps even more important, they also destroy or delay the regrowth of much of the grass and shrub vegetation, which hinders tree growth. As a result, seedlings of intolerant species have adequate time to develop good crowns above the general tree and shrub canopy.

Removal of major shrubs and residual understory trees without additional site preparation results in only a slight advantage over no treatment. The low layer of small shrubs and grass remains as a competition barrier that precludes good seedling establishment and growth.

Complete lack of seedbed preparation discriminates against larch. Larch seedlings that do become established on natural forest floor cannot compete successfully. Residual understory trees of other species, shrubs, and grasses compete vigorously with the newly established tree seedlings. Some of the more shade-tolerant species, particularly Douglas-fir, are better adapted to cope with this competition and consequently have a relative advantage over larch and other intolerant species on natural forest floor.

These two studies included no direct comparison of seedling development on burned and dozer-scarified seedbeds--the two methods most commonly used in larch forests. However, another study comparing these two methods indicated that larch trees up to

13 years old grew about one-third faster on broadcast-burned areas than they did on dozer-scarified seedbed.[9] This growth difference is probably due to better reduction of vegetative competition, less soil compaction, and the availability of more nutrients on the burned seedbeds. How long these differences persist is still unknown.

The overstocking on all the seedbeds in these studies--most severe on the burned and scarified areas--demonstrates that the seed source should be removed when sufficient seedlings have become established to fulfill the manager's minimum stocking objectives. Natural variation in seed production, germination, and seedling survival makes precise regulation of stocking difficult when using natural regeneration systems. Some overstocking is practically inevitable following especially favorable years or if seed trees are inadvertently left too long, as occurred in these studies. Under these conditions, even untreated seedbeds can overstock, particularly with the more tolerant species.

Even though seedling growth, particularly on burned and scarified areas, has been good up to this point, these heavy stand densities will suppress future growth.[10] To maintain a vigorous stand and to capitalize on the rapid juvenile growth characteristic of larch, cleaning is necessary. On good mineral soil seedbeds, species composition and tree vigor are always good, and cleaning can produce a thrifty, well distributed stand composed of several species including larch, spruce, lodgepole pine, Douglas-fir, and subalpine fir. Conversely, where there has been little or no seedbed treatment, the intolerant trees--particularly larch--are in the minority, have already declined in vigor, and appear to be poor prospects for future management. As a result, the alternatives available for selection of species to favor in cleaning are limited to the more tolerant trees.

---

[9] Roe, A. L., R. C. Shearer, and W. C. Schmidt. Management of western larch. (Manuscript in preparation)

[10] Schmidt, Wyman C. Growth opportunities for young western larch. U.S. Forest Serv. Res. Note INT-50, 4 pp. 1966.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

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

USDA Forest Service
Research Note INT-94

1969

IDENTIFYING WEATHER SUITABLE FOR PRESCRIBED BURNING[1]

William R. Beaufait and William C. Fischer[2]

ABSTRACT

Fire managers require 24-hour records of temperature, relative humidity, and windspeed to use fire efficiently and effectively. When carefully calibrated and interpreted, modified hygrothermographs provide minimum instrumentation to obtain these records. An actual case of record interpretation and use is included.

Prescribed fire is being used as a management tool on an increasing acreage each year. Burns are being scheduled during dry seasons when danger of escape requires careful assessment of fire weather. Furthermore, growing concern for management of atmospheric resources will dictate scheduling of fire treatments to coincide with weather that minimizes the amount of airborne particulates and reduces smoke in valley bottoms.

The Society of American Foresters (1958) defines prescribed burning as the "Skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture . . . required to accomplish certain planned benefits . . . ." Both fuel and soil moisture are dependent upon recent weather history. Prescribed fire planning, therefore, must be based on a complete record of current weather.

Standard fire-weather observations are typically made in the afternoon. This practice ignores diurnal variation in relative humidity and temperature. Windspeed, of critical importance to a fire's spread, is rarely observed for more than a few minutes at one time during the afternoon. Obviously, gaps in local weather intelligence hide many opportunities for conducting prescribed fires.

---

[1]The Northern Region and the Intermountain Forest and Range Experiment Station are jointly supporting a series of studies of prescribed fire and their forest management applications. Groups of scientists are investigating the effects of a wide range of fire intensities and their impacts on timber regeneration, watershed values, wildlife habitat, and atmospheric resources. This publication is the first of a series reporting the results of these efforts.

[2]Respectively, Principal Research Forester and Research Forester stationed at the Northern Forest Fire Laboratory, Missoula, Montana.

Variation due to change in elevation must also be identified in mountainous terrain. In certain situations, elevation differences can be even more important than diurnal changes in temperature and relative humidity.

Fire managers have teamed with Weather Bureau and private meteorologists to produce and use forecasts geared to the special needs of fire use. The forecaster performs his best service when he can advise the fire manager how tomorrow's weather will be different from today's. Forecasters require more information than provided by standard fire-weather observations because prescribed fires are scheduled to take advantage of any burning period appropriate to burning objectives.

Fire managers must also assess potential fire behavior as it may change with topography and available fuels. For example, a burning unit may be shielded from normal surface winds but subject to local thermal air movement that varies greatly with time of day. Such intimate knowledge of local weather can be gained only through 24-hour records of wind, temperature, and relative humidity specific to the area under study.

Continuous weather records can be obtained without expensive or cumbersome recording equipment. Hygrothermographs are easily modified to provide records adequate to prescribed burning needs. Fischer et al. (1969) have added a wind-recording arm to a hygrothermograph (fig. 1) to obtain data on diurnal wind patterns as an aid in scheduling prescribed fires.

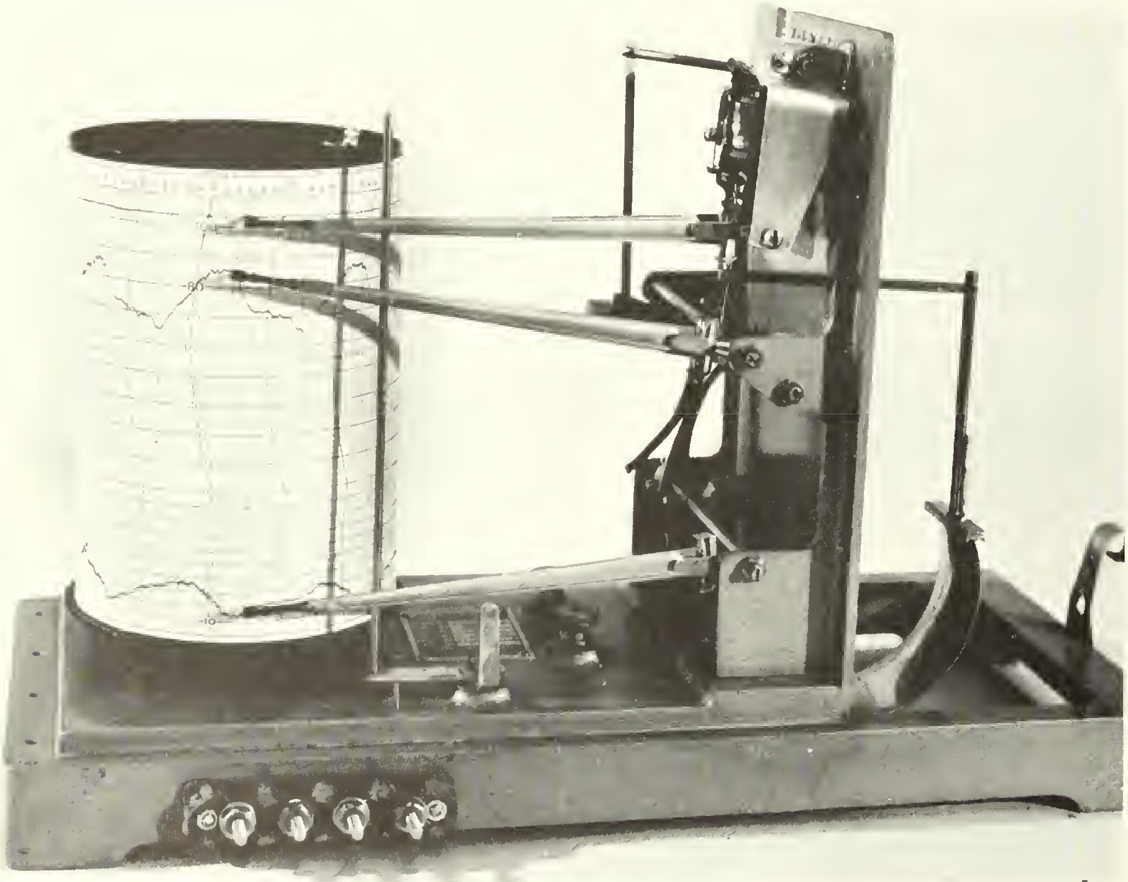


Figure 1.--A hygrothermoaerograph (HTAG). The upper arm records wind movement as transmitted from a contacting, totalizing-type anemometer.

USING CONTINUOUS WEATHER RECORDS

The following examples are taken from a large-scale study of prescribed fire effects in northwestern Montana. They illustrate burning conditions typical in mountainous terrain.

Prescribed burning decisions are frequently based solely on weather records from valley bottom stations which are common at many administrative sites. We installed both a standard valley bottom station and another station at the elevation of our burning sites (fig. 2). Figure 3 is a comparison of actual hygrothermograph records from these two stations: Stillwater Bench (3,200 feet) and a higher site on the upper third of the adjacent slope of Keith Mountain (4,500 feet).

Close inspection of the lower chart in figure 3 reveals typical diurnal fluctuation in temperature and relative humidity at the 3,200-foot site. A similar trend is discernible at the 4,500-foot site, but without both temperature and relative humidity extremes. The nighttime temperature and relative humidity values at Stillwater Bench indicate the presence of a typical nocturnal inversion in the valley. During the night, temperatures are higher and relative humidities are lower at Keith Mountain than at Stillwater Bench. The position on the slope of the Keith Mountain station has placed it above the cool, moist air of the valley. For an explanation of inversion-causing phenomena see Cramer (1961).

Figure 2.--Relative location of Stillwater Bench (foreground) and Keith Mountain (upper slope) weather stations.

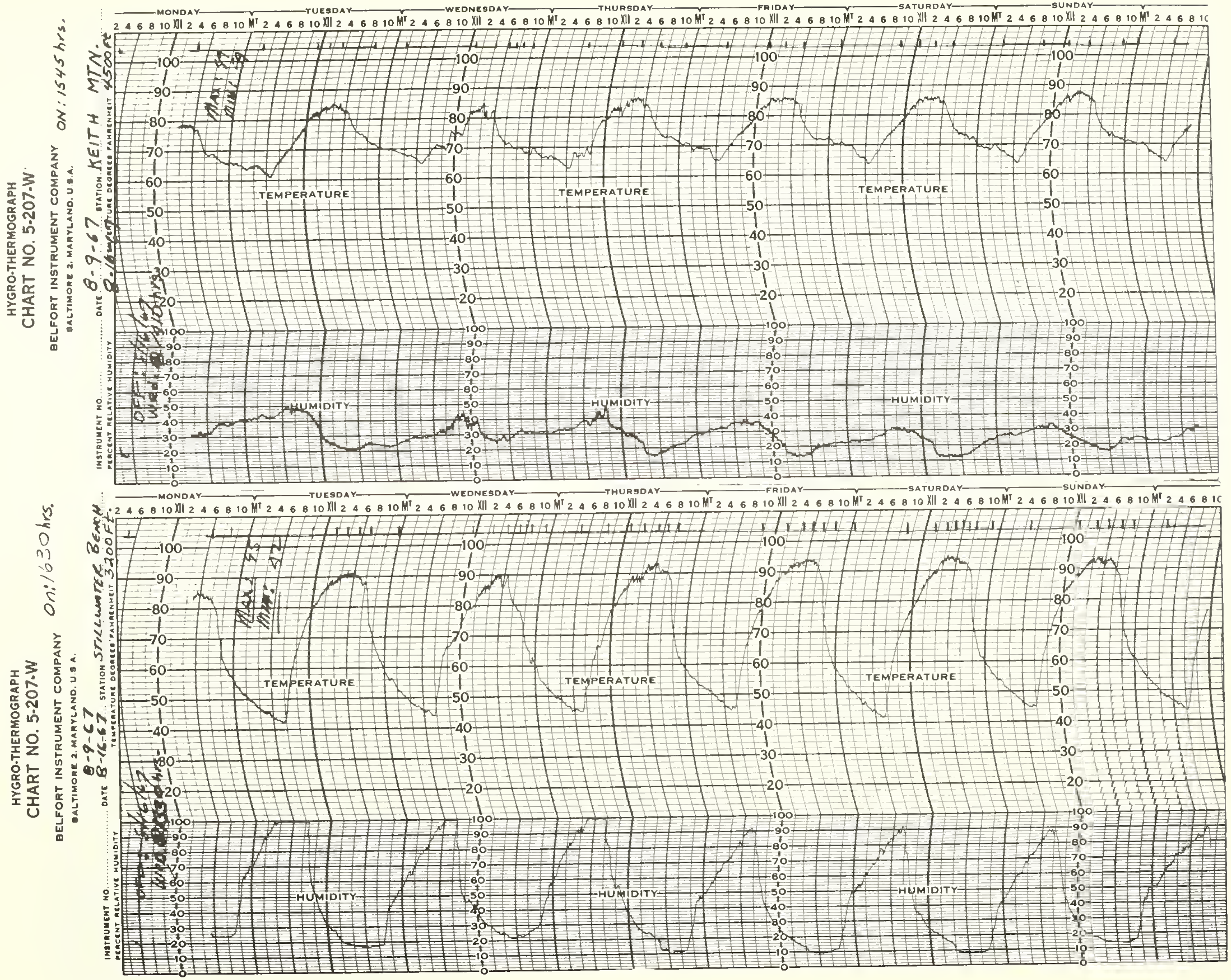


Figure 3.--HTAG charts from fire-weather stations at 4,500 feet (upper chart) and 3,200 feet (lower chart) at Miller Creek Block, August 8-15, 1967.

The effect of the difference between conditions at the two stations can be shown in terms of National Fire-Danger Rating System Fine Fuel Moisture. Figure 4 compares Fine Fuel Moisture values for Stillwater Bench and Keith Mountain at hourly intervals. Since values were calculated from the temperature and relative humidity records shown in figure 3, the trends they show are very similar to those on the hygrothermograph records.

For the days represented in the charts, 1600-hour Fine Fuel Moisture and relative humidity values were compared with 24-hour averages of fine fuel moisture and relative humidity. Two different pictures of fire-weather conditions emerged, as shown in table 1. According to the 1600-hour records of fine fuel moisture and relative humidity, more severe fire weather was recorded at the lower elevation station on Stillwater Bench than at Keith Mountain. The 24-hour averages, however, contradict this assumption. We feel that the 24-hour records more realistically characterize the effects of local weather on fuel moisture than do the once-per-day observations.

Burning objectives and air quality considerations should determine the windspeed permitted during treatment. Our prescription required windspeeds be less than 5 m.p.h. For the period represented in figure 3, wind usually ceased at about 2000 hours. Had the temperature and relative humidity conditions been favorable, ignition would be planned for this hour. In this instance, burning plans were canceled.

Continuous, onsite weather records contributed significantly to burning success. Actual weather conditions on the study area could easily have been misjudged if: (1) valley bottom fire-weather station data alone had been used, or (2) once-daily observations had been relied upon to characterize the entire 24-hour period.

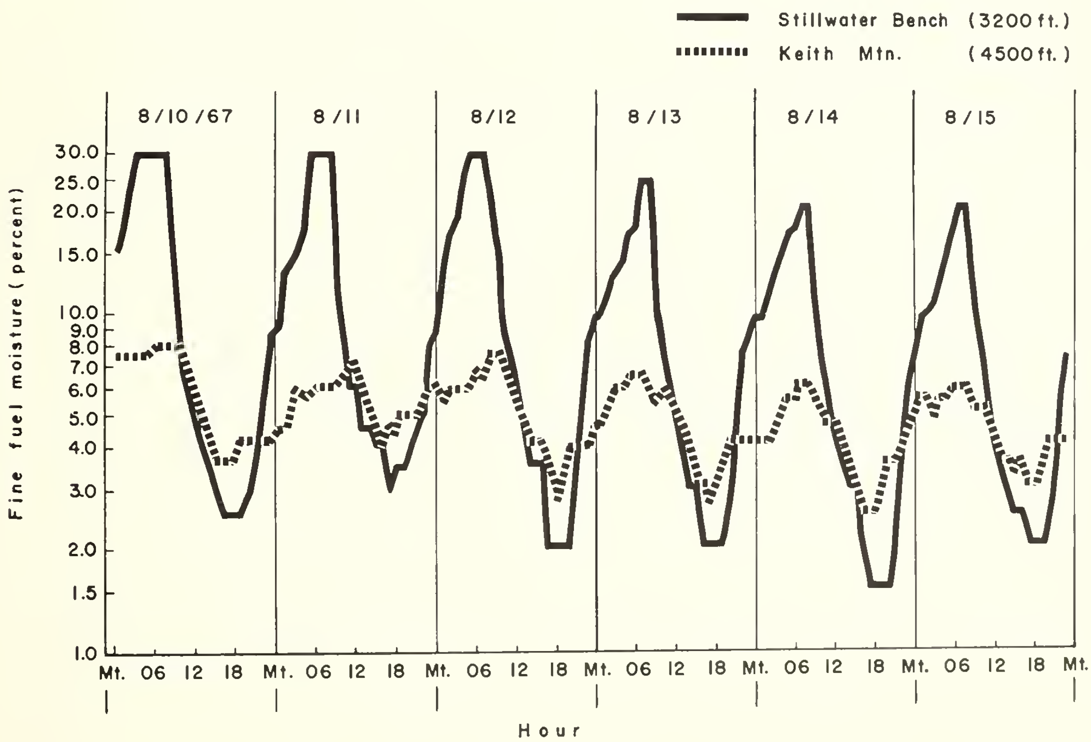


Figure 4.--National Fire-Danger Rating System Fine Fuel Moisture computed at hourly intervals for Stillwater Bench and Keith Mountain stations.

Table 1.--Fine Fuel Moisture and relative humidity--recorded and calculated averages for Stillwater Bench (3,200 feet) and Keith Mountain (4,500 feet), 1967

Date	1600-hour Fine Fuel Moisture	1600-hour relative humidity	24-hour average Fine Fuel Moisture	24-hour average relative humidity
	Percent	Percent	Percent	Percent
		STILLWATER BENCH		
August 10	2.0	18	13.3	52
11	4.0	25	11.0	50
12	2.0	20	11.6	54
13	2.0	13	8.6	42
14	1.5	10	7.7	40
15	2.5	15	8.4	38
6-day mean	2.3	16.8	10.1	46
		KEITH MOUNTAIN		
August 10	3.5	22	6.4	42
11	4.0	24	4.8	40
12	3.5	16	5.5	34
13	2.5	14	4.5	27
14	2.5	13	4.2	22
15	3.0	18	4.3	24
6-day mean	3.2	17.8	5.0	30

IMPORTANCE OF THE EXAMPLE

The combination of meteorological events presented above is not unique in mountainous terrain. Hayes (1942) described a frequent "inversion of fire behavior . . . with most dangerous conditions in the thermal belt . . . ." Barrows (1951) stressed the importance of Hayes' findings when evaluating nighttime fire behavior in the northern Rocky Mountains. Similarly, in Canada, both MacLeod (1948) and MacHattie (1966) stressed the correlation between low maximum night relative humidities and low fuel moistures. MacLeod also observed, "In the absence of rain, relative humidity is the only nocturnal weather factor which has a significant effect on forest fuel moisture in standing timber."

Gwinner (1965), in his study of fire danger as related to airmass in the Ouachita Mountains of Arkansas and Oklahoma, concluded that ". . . in polar air, 24-hour burning conditions are definitely more severe on ridgetops than in valley bottoms even though afternoon fire-danger ratings differ little between the two locations."

This example has provided three lessons for prescribed fire planning: (1) Temperature inversions can create weather conditions on a burning site quite unlike those at valley bottom weather stations; (2) 24-hour records may reflect drying conditions different from those logged at midafternoon observations alone; and (3) diurnal wind patterns, if known, can provide opportunities for burning which might otherwise be ignored.

Fire managers will need to use all weather data available to aid in making intelligent burning decisions. Hygrothermograph records, judiciously interpreted, can make their tasks a bit lighter.

LITERATURE CITED

Barrows, J. S.
1951. Fire behavior in northern Rocky Mountain forests. U.S. Forest Serv., N. Rocky Mountain Forest and Range Exp. Sta. Pap. 29, 103 pp., illus.

Cramer, Owen P.
1961. Adjustment of relative humidity and temperature for differences in elevation. U.S. Forest Serv., Pacific Northwest Forest and Range Exp. Sta. Res. Pap. 43, 21 pp.

Fischer, William C., William R. Beaufait, and Rodney A. Norum.
1969. The hygrothermoaerograph--construction and fire management applications. USDA Forest Serv. Res. Note INT-87, 8 pp., illus.

Gwinner, Myron W.
1965. Forest-fire danger as related to airmass in the Ouachita Mountains. U.S. Forest Serv. Res. Note SO-21, 4 pp., illus.

Hayes, G. L.
1942. A discussion of hygrographs. U.S. Forest Serv., N. Rocky Mountain Forest and Range Exp. Sta. Res. Note 25, 6 pp., illus.

MacHattie, L. B.
1966. Relative humidity in Rocky Mountain forests of southern Alberta in summer. Can. Dep. Forest., Forest Fire Res. Inst. Inform. Rep. FF-X-1, 53 pp., illus.

MacLeod, J. C.
1948. The effect of night weather on forest fire danger. Can. Dep. Mines and Resources, Forest Fire Res. Note 14, 29 pp., illus.

Society of American Foresters.
1958. Forest terminology. Ed. 3, 97 pp. Soc. Amer. Forest.: Washington, D. C.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

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

USDA Forest Service
Research Note INT-95

1969

MOUNTAIN PINE BEETLE INFESTATIONS IN RELATION TO LODGEPOLE PINE DIAMETERS

Walter E. Cole and Gene D. Amman
Research Entomologists

ABSTRACT

*Tree losses resulting from infestation by the mountain pine beetle (*Dendroctonus ponderosae *Hopkins) were measured in two stands of lodgepole pine (*Pinus contorta *Dougl.) where the beetle population had previously been epidemic. Measurement data showed that larger diameter trees were infested and killed first. Tree losses ranged from 1 percent of trees 4 inches (d.b.h.) to 87 percent of those 16 inches and greater d.b.h. Numbers of adult beetle emergence holes averaged 1.3 per square foot of bark area in trees 7 inches d.b.h. and 62 in trees 18 inches and greater d.b.h. The observations indicate that large infestations of mountain pine beetle depend on the presence of large diameter trees within a stand of lodgepole pine, thus implying that beetle population growth is food-limited.*

The infestation by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), that started in the early 1960's in western Wyoming and eastern Idaho, has destroyed over 3 million lodgepole pine (*Pinus contorta* Dougl.) trees in that area. As a result, studies were conducted to determine if a relationship exists between beetle populations and the sizes of the trees that are infested. Specifically, the objectives were to (1) verify the relationship between infestations of the mountain pine beetle and the diameter of lodgepole pine within large stands, and (2) demonstrate the relationship between diameter of lodgepole pine and numbers of emergence holes made by brood adults.

Gibson (1943) observed that the mountain pine beetle attacked a greater proportion of large rather than small diameter lodgepole pine trees. Hopping and Beall (1948) found a direct relationship between tree diameter and percentage of trees infested by the mountain pine beetle. Bedard (1938, 1939) found in western white pine that more mountain pine beetles developed to maturity per square foot of bark in the larger diameter trees. Reid (1963) reported similar findings for the mountain pine beetle in lodgepole pine. Shepherd (1966) indicated that the beetle has evolved a searching image (large dark objects against a light background) for large diameter trees. The evolution of such behavior should be advantageous when the greater survival of beetles in trees of large diameter is considered.

METHODS

Two stands of lodgepole pine were selected in which the mountain pine beetle population had risen to epidemic level for several years but recently has declined to a relatively low level. These were located in the Teton National Forest and Teton National Park in northwestern Wyoming. Twenty 1/10-acre nonvariable plots were located in a grid pattern within a 2-mile-square unit within each of the two stands. All trees that were 4 inches and larger in diameter were measured and the year of death for each tree was determined within these plots.

The following characteristics were used to determine the year in which the tree was killed: (1) foliage green, fresh boring frass, eggs or larvae present--tree killed in current year; (2) foliage bright orange to straw color--tree killed in previous year; (3) foliage dull orange and most retained--tree killed in second year past; (4) foliage dull orange to gray and most lost--tree killed in third year past; (5) no foliage, most small twigs lost which had supported needle fascicles--tree killed in fourth year past; (6) bark peeling--tree dead for 5 or more years.

In the plots within one 2-mile-square unit, the numbers of emergence holes were counted on two 6-inch-square areas of bark selected at random at diameter breast height (d.b.h.) on each tree that had been killed by the mountain pine beetle.

RESULTS AND DISCUSSION

Sizes of trees killed.--The results demonstrate that the mountain pine beetle strongly favors the trees of larger diameter each year, as well as over the life of the infestation, and verify the observations of Gibson (1943) and Hopping and Beall (1948). As the larger diameter trees are killed, the beetles infest the residual smaller diameter trees or possibly migrate in search of the larger trees in adjoining areas.

Estimates of the average diameter of trees killed by the beetle per year gave standard errors that were usually less than 10 percent of the mean. The proportions of trees killed in the various diameter classes in the two units were remarkably similar and varied from 1.1 percent in the 4-inch-diameter class to 87.5 percent in the 16-inch-and-greater class (fig. 1). Correlations between diameters of trees killed and year of kill were highly significant ($r = 0.46$ and 0.58, $P < 0.01$), with the larger trees being selected by the beetle in the early years of the infestation (fig. 2). In the latter stages of the infestation (beetle and infested tree populations decreasing) the beetles were working in the smaller diameter trees. This is not to infer that all nonsurviving trees were killed by the mountain pine beetle. The proportion of lodgepole trees killed by the beetle is shown in table 1.

The pattern of infestation, i.e., average diameter killed by percent of trees killed over years of infestation, is shown in figure 3. Again, the preference of the beetle for the larger diameter trees by year is evident.

The infestations rose from approximately 0.5 to 5 trees per acre in 1962 to a peak of 26 to 31 trees per acre in 1964. They then declined to 2 to 3.5 trees per acre by 1967, when most of the larger diameter trees had been killed. The intense period of the infestation was relatively short, lasting approximately 6 years (fig. 4). The data of Gibson (1943) for an infestation occurring during the 1930's indicate a comparable period of time. The similarity in the three curves depicting the percentages of trees killed by year for these plots supports the accuracy of our determination of the year of tree kill.

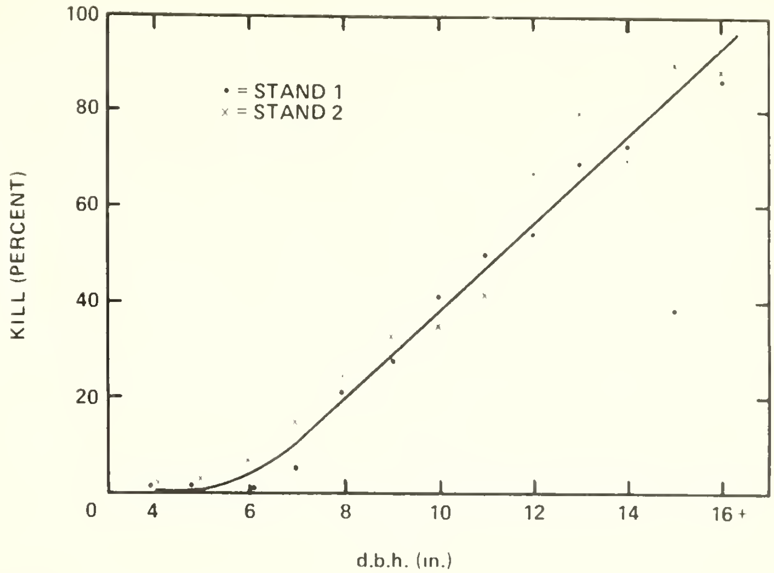


Figure 1.--Proportion of lodgepole pine trees killed within the combined study stands, by diameter class, 1962-67.

In the two stands, 155 trees, or 68 percent, and 192 trees, or 71 percent, of those trees that were 4 inches and greater in diameter were still living in 1967. Survival varied from 100 percent in the 4-inch-diameter class of trees to 12.5 percent in the 16-inch-and-greater class.

Not all dead trees in the study areas were killed by the mountain pine beetle. It is evident that *Ips* species infested and killed some of the smaller diameter trees (table 1). It is also assumed that a relationship exists between the mountain pine beetle and *Ips*; that is, the *Ips* alone might not have caused as high a loss as it appears. *Ips* infest the trees above the part infested by the mountain pine beetle.

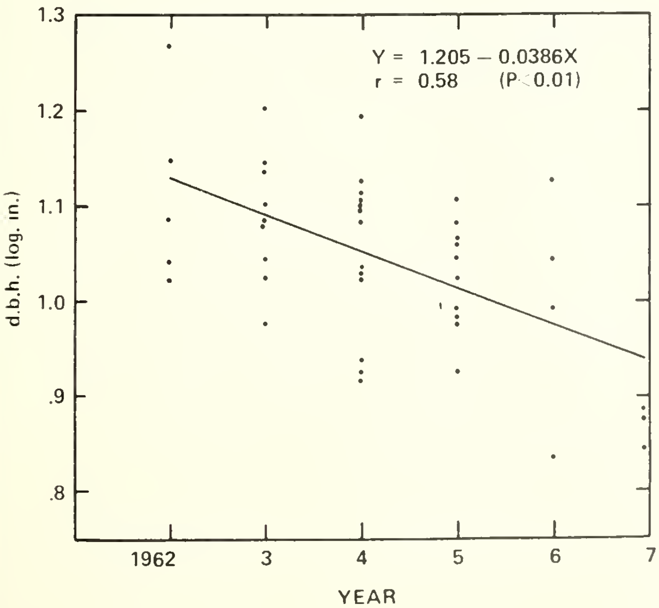


Figure 2.--Correlation between diameters of lodgepole pine trees killed by the mountain pine beetle, and year of kill; for example, within study stand 2, 1962-67.

Table 1.--Proportion of lodgepole pine trees by diameter class killed per acre by the mountain pine beetle, 1962-67

Diameter class (inches)	Number of trees/acre				Percent killed by MPB
	Surviving	Killed by MPB	Killed by other causes[1]	Total	
PACIFIC CREEK - TETON NATIONAL FOREST					
Stand 1					
4	12.5	0.0	0.0	12.5	0.0
5	17.5	.0	1.0	18.5	.0
6	22.5	.0	.0	22.5	.0
7	25.0	1.5	1.5	28.0	5.6
8	17.5	5.0	1.5	24.0	20.8
9	19.5	8.0	.5	28.0	28.6
10	14.0	10.0	.0	24.0	41.7
11	9.5	10.0	.5	20.0	50.0
12	5.5	6.5	.0	12.0	54.2
13	4.0	9.0	.0	13.0	69.2
14	2.0	5.5	.0	7.5	73.0
15	4.0	2.5	.0	6.5	38.5
16	.5	3.5	.0	4.0	87.5
17	.5	3.0	.0	3.5	85.7
18+	.5	3.5	.0	4.0	87.5
Totals	155.0	68.0	5.0	228.0	29.8
PILGRIM CREEK - TETON NATIONAL PARK					
Stand 2					
4	21.5	0.0	2.5	24.0	0.0
5	25.0	.5	1.0	26.5	1.9
6	37.0	3.0	2.0	42.0	7.1
7	37.0	7.0	1.5	45.5	15.4
8	27.5	9.0	.0	36.5	24.7
9	15.0	.0	1.5	24.5	32.7
10	15.0	8.5	1.0	24.5	34.7
11	6.0	5.0	1.0	12.0	41.7
12	4.5	9.0	.0	13.5	66.7
13	1.5	6.0	.0	7.5	80.0
14	1.0	3.0	.0	4.0	75.0
15	.5	4.5	.0	5.0	90.0
16	.0	1.0	.0	1.0	100.0
17	.0	.5	.0	.5	100.0
18+	.5	2.0	.0	2.5	80.0
Totals	192.0	67.0	10.5	269.5	24.9

[1]Most killed by *Ips* species.

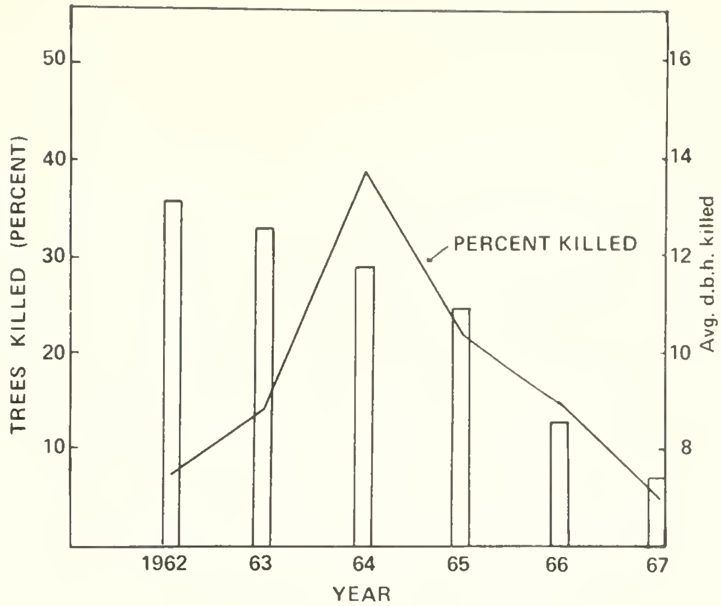


Figure 3.--Proportion and average diameter of lodgepole pine trees killed, by year of infestation; for example, within study stand 2, 1962-67.

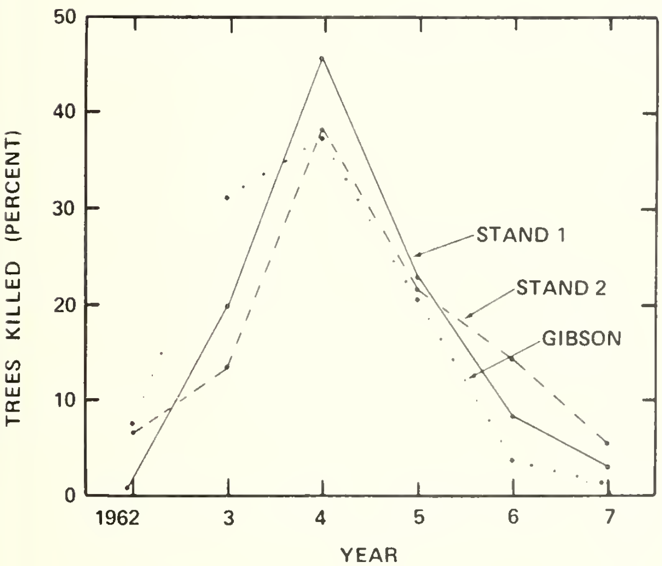


Figure 4.--Comparison of percents of trees killed by the mountain pine beetle in stands 1 and 2 during 1962-67 with those reported by Gibson (1943) for an infestation during the 1930's.

Relation of beetle population to diameter.--The number of emergence holes made by brood adults which completed development and left the tree was usually greater in the larger diameter trees. Average numbers of emergence holes varied from 1.3 per square foot of bark area for trees 7 inches d.b.h. to 62 for trees 18 inches and greater in d.b.h. (fig. 5). Reid (1963) observed that beetle survival increased with diameter of tree. Amman[1] also noted that the number emerging per hole increases as the density of beetles increases per unit area of bark. Therefore, the number of beetles emerging from large diameter trees would be much greater than indicated by emergence holes.

[1]Unpublished data, authors' files.

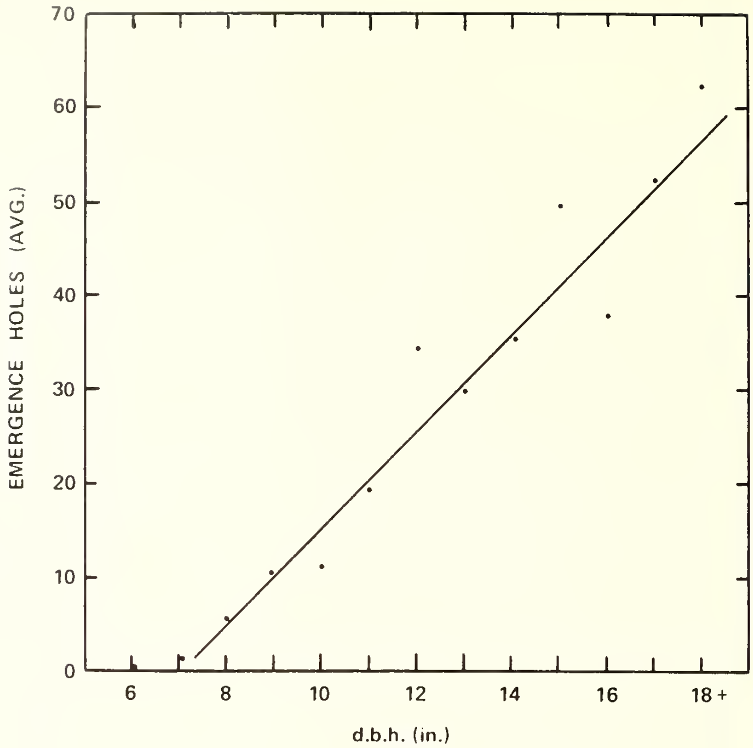


Figure 5.--Average number of emergence holes per square foot of bark, by diameter class.

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 boles of lodgepole pines of different diameter were infested to different heights by the mountain pine beetle. The figures by Cahill for infestation height and our figures on beetle emergence were used to calculate the populations of beetles produced in trees. These showed beetle production could vary from 300 for trees 8 to 9 inches d.b.h. to more than 15,000 for trees 18 inches d.b.h.

Assuming an infestation rate of 12 female beetles per square foot of bark surface, the rate commonly observed in the field, and a 1:1 sex ratio, 24 beetles per square foot would be sufficient to infest and kill a tree. Thus, a tree 8 to 9 inches d.b.h. would produce only one-third enough beetles to infest and kill a green tree (fig. 6). Only when the infested trees are 12 to 13 inches d.b.h. do they produce a surplus of beetles. And if we assume that one-third to one-half of the beetles that emerge are killed in flight (a conservative assumption), then 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.

CONCLUSIONS

The conclusions derived from this study follow: (1) The beetle strongly favors the larger diameter trees each year, as well as over the life of the infestation; and (2) if only trees 14 inches and greater in diameter produce enough beetles to maintain or increase the infestation and if, in fact, the beetle progressively destroys its preferable food supply, then this insect is apparently food-limited in its population growth within a given area. Such a decrease in food supply could be a stimulus for search. It then follows that the searching capabilities of the insect may also be a factor limiting population growth.

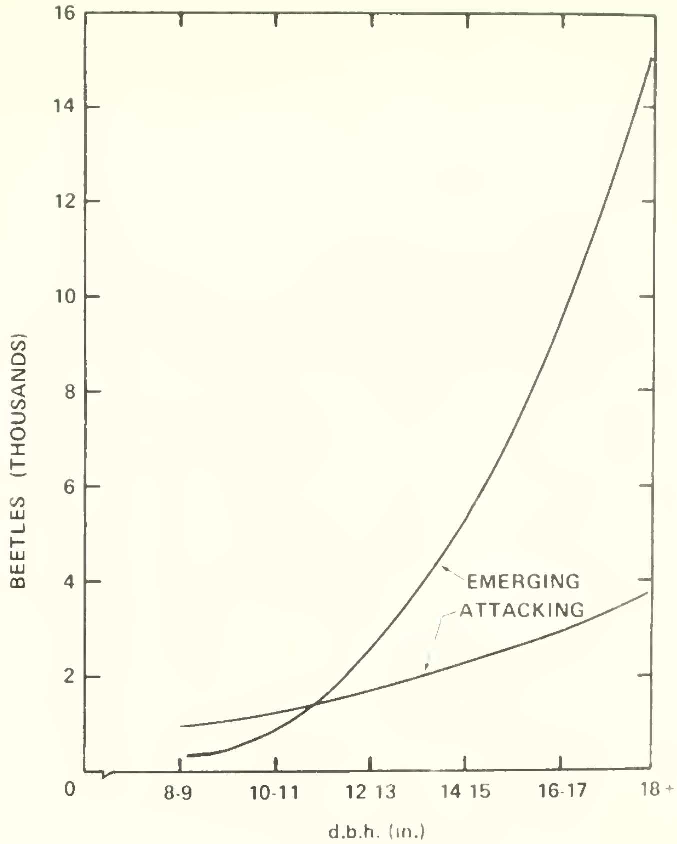


Figure 6.--A comparison of the number of beetles that emerged from trees, by diameter class, with the number of beetles sufficient to infest a tree within a corresponding diameter class.

REFERENCES

Bedard, W. D.
1938. A study of mountain pine beetle infestations in western white pine. Unpub. Rep., Forest Insect Laboratory, Coeur d'Alene, Idaho, 47 pp., illus.

Bedard, W. D.
1939. A study of mountain pine beetle infestations in western white pine. Unpub. Rep., Forest Insect Laboratory, Coeur d'Alene, Idaho, 47 pp., illus.

Cahill, Donn B.
1960. The relationship of diameter to height of attack in lodgepole pine infested by mountain pine beetle. U.S. Dep. Agr., Forest Serv., Intermountain Forest and Range Experiment Station Res. Note 78, 4 pp.

Gibson, A. L.
1943. Status and effect of a mountain pine beetle infestation on lodgepole pine stands. Mimeo. Rep., Forest Insect Laboratory, Coeur d'Alene, Idaho, 34 pp.

Hopping, G. R., and G. Beall.
1948. The relation of diameter of lodgepole pine to incidence of attack by the bark beetle, *Dendroctonus monticolae* Hopkins. Forest. Chron. 24: 141-145.

Reid, R. W.
1963. Biology of the mountain pine beetle, *Dendroctonus monticolae* Hopkins, in the east Kootenay Region of British Columbia. III. Interaction between the beetle and its host, with emphasis on brood mortality and survival. Canad. Entomol. 95: 225-238.

Shepherd, R. F.
1966. Factors influencing the orientation and rates of activity of *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae). Canad. Entomol. 98: 507-518.

FOREST SERVICE CREED

The Forest Service of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing nation.

Research Note

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

USDA Forest Service
Research Note INT-96 1969

MOUNTAIN PINE BEETLE EMERGENCE IN RELATION TO DEPTH OF LODGEPOLE PINE BARK

Gene D. Amman, Research Entomologist

ABSTRACT

Phloem thickness is one of the important factors affecting mountain pine beetle (Dendroctonus ponderosae *Hopkins*) *survival in lodgepole pine* (Pinus contorta *Dougl.*). *Emergence holes made by adults which completed larval development within the trees were counted on two 6- by 6-inch areas of bark on each tree killed by the mountain pine beetle on twenty 1/10-acre plots. Various tree, stand, and site factors were also measured. Emergence holes ranged from none in bark 0.06 inch thick to an average of 120 per square foot where the bark was 0.18 inch thick. Emergence holes were most closely correlated with bark depth, and varied with stand density and plot elevation. The greatest proportion of thick-barked trees was in the large diameter classes.*

Infestations of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) appear to depend on trees of large diameter. Cognizant of this, we posed the question, what difference that might contribute to successful population buildup of the mountain pine beetle exists between lodgepole pine trees (*Pinus contorta* Dougl.) of small and large sizes? Hopping and Beall (1948) and Gibson (1943) showed that greater proportions of large rather than small diameter lodgepole pine trees were killed by the mountain pine beetle. Bedard (1938), in studies of mountain pine beetles in western white pine (*P. monticola* Dougl.), found that trees 10 inches in diameter at breast height (d.b.h.) produced proportionally fewer beetles than trees of larger diameter. Reid (1963) studied factors that affect populations of the mountain pine beetle. He concluded that survival was most closely related to diameter of the host tree but stated that the reason for this was not apparent. Cole and Amman (1969) verified the relation between lodgepole pine of large diameter and the mountain pine beetle in the present Wyoming infestation.

Depth of phloem in small and large trees is the most obvious difference related directly to bark beetles. Phloem serves as food for larvae of the mountain pine beetle. Thus the following hypothesis was formed: the number of mountain pine beetles completing development within a given area of bark depends on depth of phloem. This study was designed to test this hypothesis.

METHODS

Tree, stand, and site measurements were obtained from a portion of a lodgepole pine forest that had been infested by the mountain pine beetle for several years. These measurements were subjected to a multiple correlation analysis to determine which explained the most variance in numbers of beetle emergence holes observed in the trees.

Tree, stand, and site measurements.--Twenty 1/10-acre plots were located in a grid pattern over a 2-mile-square portion of a lodgepole pine forest on the Teton National Forest where no effort had been made to control the mountain pine beetle. The year in which each tree was killed by the beetle was determined by using foliar characteristics (Cole and Amman 1969).

Variables measured on each tree were the numbers of holes made by emerging beetles that had completed development on two 6- by 6-inch areas of bark selected at random at d.b.h., the depth of bark in the center of each area (ridges and scales excluded), tree d.b.h., and tree height. In addition, the number of trees (4 inches d.b.h. and greater) per one-tenth acre (stand density) and the elevation of the plot were recorded.

Because all trees were dead, it was essential to know (1) if the numbers of emergence holes could be used as a reliable indicator of numbers of beetles completing development and emerging from a given area of bark, and (2) if total bark depth could be used as an indicator of phloem depth. Significant relations between numbers of emerging beetles and emergence holes were established in the field for caged lodgepole pine (Reid 1963) and in slabs in laboratory cages (correlation coefficient 0.85).[1]

Bark measurements of 30 trees ranging from 7 to 19 inches d.b.h. showed a significant relation (r = 0.81) between phloem depth and total bark depth. These findings indicate that emergence holes reliably indicate numbers of emerging beetles and that total bark depth of a dead tree is a good indicator of phloem depth at the time the tree was attacked and killed by the beetle. Shrinkage was assumed to be proportional at all phloem depths in the dead trees.

Analysis.--Numbers of emergence holes were expanded to a square-foot basis. Using the largest data group (year 1964), numbers of emergence holes (the dependent variable) were machine plotted two-dimensionally over independent variables and three-dimensionally over paired combinations of independent variables. The forms of relationships were then developed manually on these plottings.

The forms were described algebraically and then subjected to a full-screen, multiple regression analysis. In this analysis, the numbers of emergence holes were fitted by least squares as a function of all additive combinations of the independent variables. Explanatory strengths of the variables were assessed on the basis of fitting order and the multiple correlation coefficients. This process was repeated for each of 3 years--1963-65. Too few trees were killed within the study area before or after these years to provide enough data for a meaningful analysis.[2]

---

[1]Unpublished data, author's files.

[2]The assistance of Chester E. Jensen, Statistician, Intermountain Forest and Range Experiment Station, Ogden, Utah, in the analysis of data and his algebraic descriptions of curves are acknowledged gratefully.

RESULTS AND DISCUSSION

Bark depth was consistently and by far the strongest independent variable each year, explaining from 23 to 62 percent of the variance in numbers of emergence holes per square foot of bark surface. Nominal gains in the multiple correlation coefficient (R^2) were contributed when stand density and plot elevation were incorporated into interaction models. Less consistent and smaller improvements in R^2 were noted for all other combinations of the independent variables.

Beetle emergence holes.--The average numbers of beetle emergence holes varied from none in bark 0.06 inch thick to 120 per square foot in bark 0.18 inch thick (table 1). Bark less than 0.10 inch thick had few emergence holes (0-12), bark 0.10 to 0.13 inch thick had moderate numbers of emergence holes (8-36), and bark 0.14 inch or greater in thickness contained large numbers of holes (34-120).

The number of emergence holes in bark of a given thickness became less with year (fig. 1). Two possible causes are intraspecific competition and natural enemies. Cole (1962) demonstrated experimentally the effect of competition among mountain pine beetle larvae. As the number of inches of egg gallery and, hence, the number of eggs per unit of bark increased, competition among the resulting larvae also increased. Consequently, survival of beetles in a given area of bark decreased. In 1963, the amount of egg gallery may have been about optimum for maximum beetle production; in the next 2 years it may have been so great that larval competition reduced beetle production.

Parasite and predator populations could also cause a decline in beetle emergence. They increase over the life of a mountain pine beetle infestation and should have exerted their greatest influence on the pine beetle population in 1965.

Table 1.--Average numbers of emergence holes made by mountain pine beetles per square foot of bark surface in lodgepole pine trees of different bark depth during 3 years

Bark depth (inch)	1963 Observations	1963 Emergence holes	1964 Observations	1964 Emergence holes	1965 Observations	1965 Emergence holes
0.06	--	--	2	0	--	--
.07	1	4	5	2	--	--
.08	--	--	8	3	2	2
.09	--	--	12	4	8	6
.10	6	33	25	14	6	8
.11	11	15	23	12	14	36
.12	11	26	23	26	11	31
.13	5	30	12	24	9	31
.14	2	80	4	61	3	43
.15	6	75	3	51	1	42
.16	2	34	2	50	1	84
.17	5	87	--	--	--	--
.18	2	120	4	83	2	36
.19	2	88	1	105	1	56

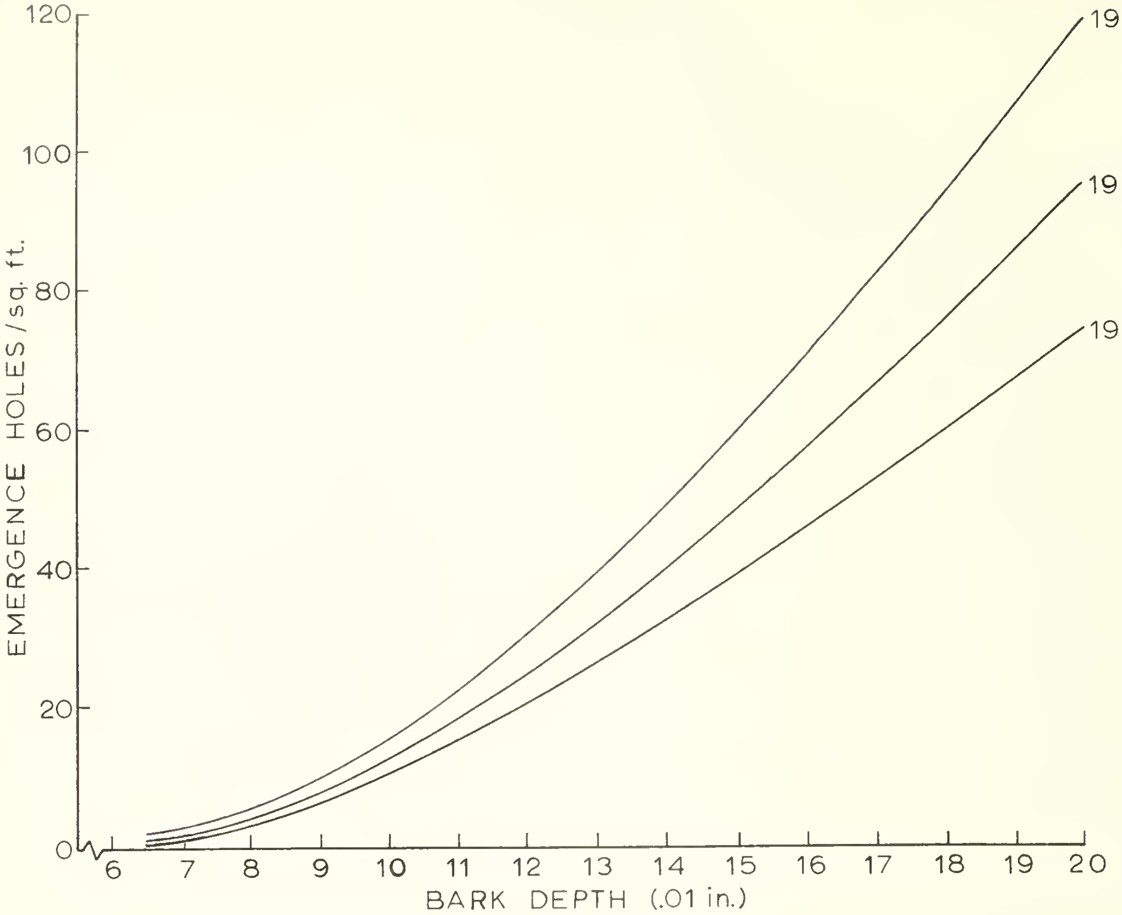


Figure 1.--The relation of mountain pine beetle emergence holes to bark depth of lodgepole pine killed.

(1963, $\hat{Y} = -9.6 + 4.111\ (100\ B-6)^{1.3}$, $R^2 = 0.44$;

1964, $\hat{Y} = -8.9 + 3.361\ (100\ B-6)^{1.3}$, $R^2 = 0.62$;

1965, $\hat{Y} = -3.0 + 2.494\ (100\ B-6)^{1.3}$, $R^2 = 0.23$).

Bark depth and d.b.h.--Bark depth was related to d.b.h. of the trees, the larger diameter trees generally having thick bark, and the smaller diameter trees usually having thin bark. Bark depth varied from an average of 0.082 inch on trees 7 inches d.b.h. to 0.161 inch on trees 18 inches d.b.h. or greater (table 2). Because phloem depth was correlated with total bark depth, the larger trees usually afforded more food for the mountain pine beetle per unit area of bark than smaller trees. However, the range in bark depth in each diameter was considerable (table 2) and it will be shown later that the relation of beetle emergence holes to d.b.h. is poor when compared to the relation to bark depth.

Factors affecting numbers of emergence holes.--In 1964 (year of peak tree mortality), bark depth explained 62 percent of the variation observed in numbers of emergence holes. Individual correlations with d.b.h., tree height, stand density, and plot elevation explained only 5 to 15 percent of the variation (table 3).

Table 2.--Average bark depth of lodgepole pine trees of different diameter killed by the mountain pine beetle

D.b.h. (inches)	Samples	Bark depth	Range
	No.	Inch	Inch
7	6	0.082	0.07-0.09
8	16	.097	.07- .13
9	33	.100	.06- .13
10	38	.101	.07- .15
11	40	.108	.08- .15
12	21	.118	.07- .15
13	32	.120	.09- .18
14	22	.126	.08- .16
15	10	.134	.12- .17
16	14	.137	.10- .19
17	12	.144	.10- .18
18+	14	.161	.11- .19

Combinations of three variables, with bark depth included in each combination, explained an additional 1 to 4 percent variation over that of bark depth alone (table 3). Combinations of four or more variables explained no additional variation. The significant independent variables appear to be bark depth, stand density, and plot elevation. These three variables explained all but 1 percent of the variation accounted for by all variables combined. The total variation explained in the numbers of emergence holes was 66 percent.

In 1963, bark depth was the most important factor measured, followed by stand density. Stand density contributed an additional 2 percent to the amount of variation explained in numbers of emergence holes over that of bark depth alone. The combination of bark depth, stand density, and elevation explained an additional 4 percent of the variation, giving a total of 48 percent, which was all but 1 percent explained by all variables combined.

Table 3.--Proportion of variance in numbers of mountain pine beetle emergence holes per square foot explained by different combinations of tree and stand factors

Variable		R^2		
		Year		
Dependent	Independent	1963	1964	1965
Emergence holes	Bark depth	0.44	0.62	0.23
	D.b.h.	.01	.06	.16
	Height	.02	.05	.02
	Stand density	.09	.15	.16
	Plot elevation	.03	.06	.14
	Bark depth X d.b.h.	.43	.63	.24
	Bark depth X height	.44	.64	.23
	Bark depth X stand density	.46	.64	.30
	Bark depth X plot elevation	.38	.66	.28
	Bark depth X stand density X elevation	.48	.65	.34
	All variables	.49	.66	.35

In 1965, stand density explained an additional 7 percent of the variation in numbers of emergence holes over bark depth alone. Again, the combination of bark depth, stand density, and elevation accounted for all but 1 percent of the variation (35 percent) explained by all variables.

In all years, the interaction between bark depth and stand density may be significant, contributing an increasing amount to R^2 over the 3 years (table 3). Trees growing in plots having the least stand density had the largest number of emergence holes for a given bark depth (fig. 2). The data do not demonstrate why this should be, but it is probably related to the ratio of phloem to dead bark. In dense stands, competition among trees may reduce the ratio.

A second interaction that may be significant is that of bark depth and plot elevation. Gibson (1943) showed that tree killing by the mountain pine beetle declined as elevation increased. I found the greatest numbers of emergence holes occurred in trees at the low elevation (7,200 to 7,400 feet). Trees at the two highest elevations (7,500 to 7,900 feet and 8,000 to 8,400 feet) had about equal numbers of emergence holes for a given bark depth (fig. 3). Although the reason for this difference is unknown, climatic factors (as they affect the insect) are probably responsible.

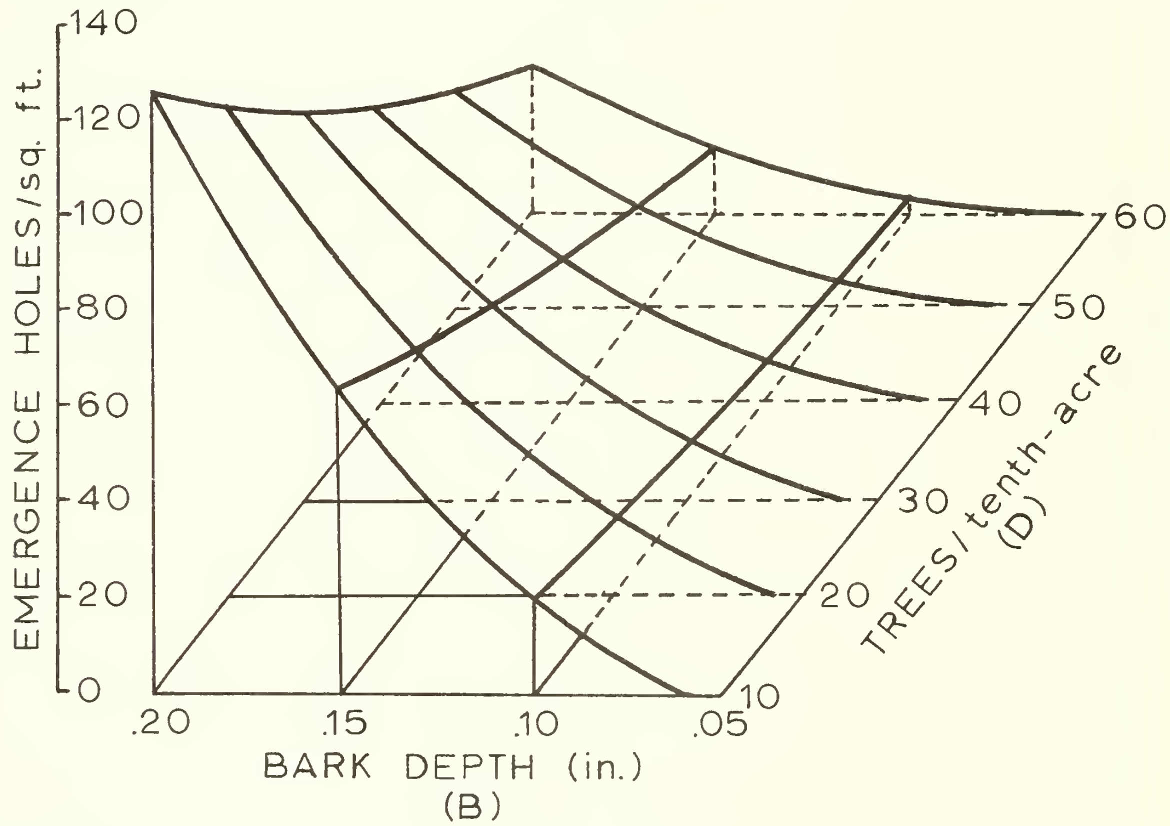


Figure 2.--The relation of mountain pine beetle emergence holes to bark depth of lodgepole pine killed in 1964 in stands of different density.

$$(\hat{Y} = -2.94 + 0.04046\ (100\ B-5)^{1.6}\ (10 - 0.1D)^{1.7}$$

$$0.06 \leq B \leq 0.20,\ 10 \leq D \leq 60;\ R^2 = 0.64).$$

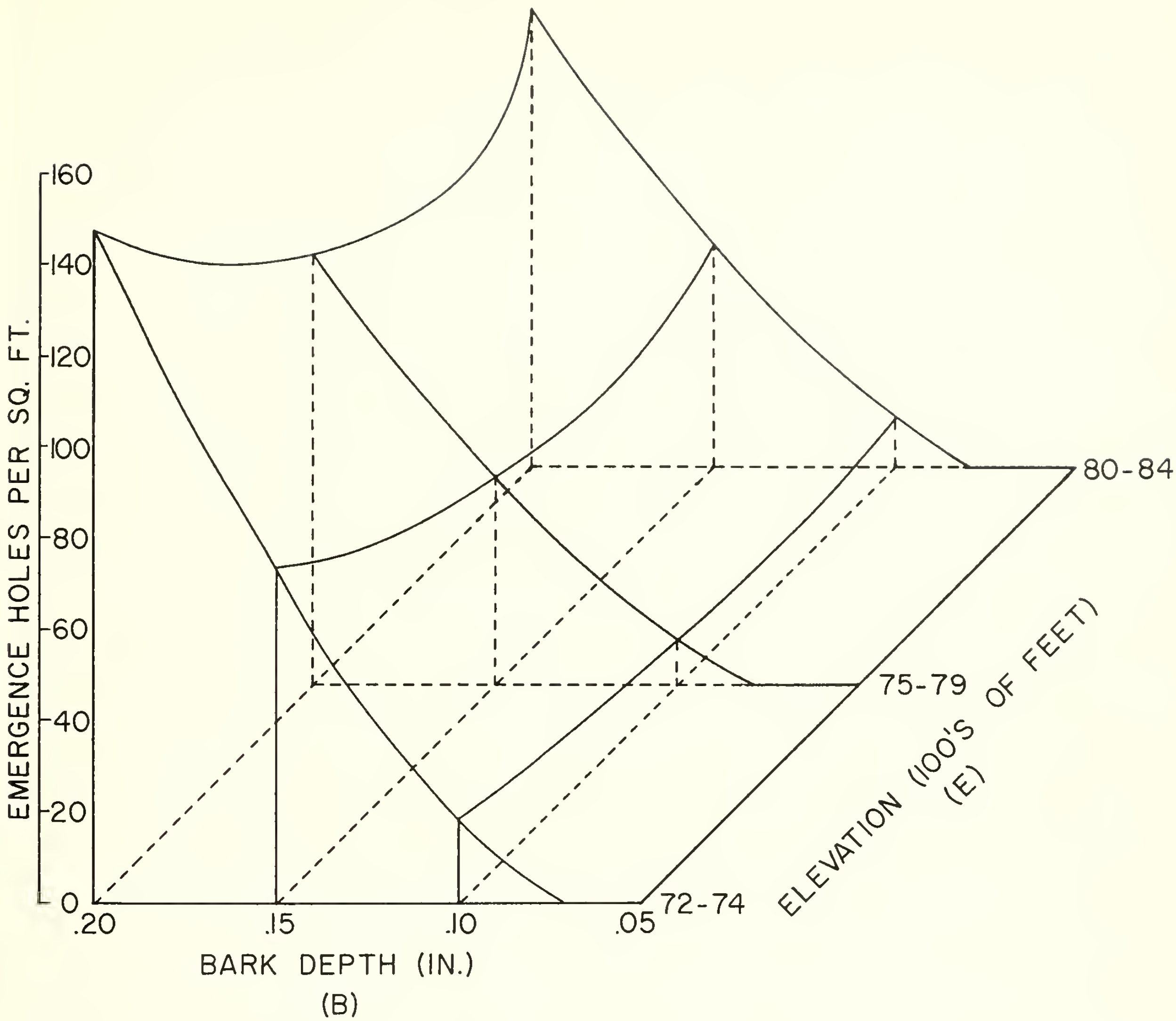


Figure 3.--The relation of mountain pine beetle emergence holes to bark depth of lodgepole pine killed in 1964 at different elevations.

$(\hat{Y} = -7.96 + 0.01571\ (100\ B-5)^{1.6}\ (E-77)^2 + 1.29\ (100\ B-5)^{1.6};$

$0.06 \leq B \leq 0.20,\ 72 \leq E \leq 84;\ R^2 = 0.66).$

CONCLUSIONS

Phloem depth (food) is probably the most important factor affecting epidemic populations of the mountain pine beetle in lodgepole pine. Although the relation of phloem depth to tree diameter is highly variable, most trees with thick phloem are large in diameter, while trees with thin phloem are usually small in diameter.

The exact role of phloem (quantity and quality) should be defined more precisely. In addition, other variables affecting beetle survival, such as intraspecific competition and natural enemies, need to be evaluated to improve predictions of mountain pine beetle populations.

REFERENCES

Bedard, W. D.
1938. A study of mountain pine beetle infestations in western white pine. Unpubl. Rep., U.S.D.A., Bur. Entomol., Forest Insect Laboratory, Coeur d'Alene, Idaho, 65 pp., illus.

Bedard, W. D.
1939. A study of mountain pine beetle infestations in western white pine. Unpubl. Rep., U.S.D.A., Bur. Entomol., Forest Insect Laboratory, Coeur d'Alene, Idaho, 47 pp., illus.

Cole, Walter E.
1962. The effects of intraspecific competition within mountain pine beetle broods under laboratory conditions. U.S.D.A. Forest Serv., Intermountain Forest and Range Exp. Sta. Res. Note 97, 4 pp.

Cole, Walter E., and Gene D. Amman.
1969. Mountain pine beetle infestations in relation to lodgepole pine diameters. USDA Forest Serv. Res. Note INT-95, 7 pp., illus.

Gibson, A. L.
1943. Status and effect of a mountain pine beetle infestation on lodgepole pine stands. Mimeo. Rep., U.S.D.A., Bur. Entomol., Forest Insect Laboratory, Coeur d'Alene, Idaho, 34 pp.

Hopping, George R., and Geoffrey Beall.
1948. The relation of diameter of lodgepole pine to incidence of attack by the bark beetle, *Dendroctonus monticolae* Hopkins. Forest. Chron. 24: 141-145.

Reid, R. W.
1963. Biology of the mountain pine beetle, *Dendroctonus monticolae* Hopkins, in the east Kootenay Region of British Columbia. III. Interaction between the beetle and its host, with emphasis on brood mortality and survival. Canad. Entomol. 95: 225-238.

Research Note

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

USDA Forest Service
Research Note INT-97 1969

POROSITY OF CHEATGRASS FUEL RELATED TO WEIGHT

J. K. Brown[1]

ABSTRACT

Porosity (expressed as the ratio of air space surrounding plant material to surface area of plant material) was determined for a low forage producing community of cheatgrass. Porosity averaged 12.5 cm.^{3}/cm.^{2} and correlated closely with weight per square meter. Estimation of porosity from weight per unit of ground area is a practical aid in assessing the flammability of cheatgrass.

Cheatgrass (Bromus tectorum L.) is a finely divided fuel that is highly flammable[2] when dry and can support rapid rates of fire spread (Barrows 1951; Klemmedson and Smith 1964). Because cheatgrass is widely distributed--occurring on at least 60 million acres in the 11 Western States (Hull 1965)--it presents a fire hazard of major concern to many land management agencies. An understanding of the factors controlling cheatgrass flammability is necessary for good management of range and forest lands.

The flammability of cheatgrass depends largely on physical properties, such as weight and porosity, and on moisture content. Porosity refers to the spacing of plant particles and is defined here as the ratio of airspace surrounding plant particles to surface area of these plant particles. The moisture content of uncured cheatgrass is physiologically controlled at a fairly high level, which can be estimated from plant coloration (Mutch 1967). When the moisture content reaches low levels (5- to 10-percent dry weight), variations in flammability probably are primarily caused by fuel weight and porosity.

Porosity is a difficult variable to determine because it requires time-consuming measurements of fuel volume and surface area. A literature search failed to reveal any porosity values for cheatgrass. This study provides such values for several densities of cheatgrass and shows that fuel weight, a relatively easy variable to measure, can be used to estimate porosity with good reliability.

---

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

[2]Flammability is defined as the relative ease with which fuels ignite and burn regardless of the quantity of the fuels. (U.S. Dep. Agr., Glossary of terms used in forest fire control. P. 13, in: Agr. Handbook 104, 24 pp. 1956.)

METHODS AND MATERIALS

An area of approximately 1 acre was sampled in August 1966. The area is on a gentle south-facing slope in northwestern Montana. Three zones containing heavy, moderate, and sparse amounts of cheatgrass were delineated by staking out the boundaries. Study plots, 10 by 25 cm. in size, were located in each zone to assure a wide range in plant densities. The heavy density zone contained 11 plots, the medium zone 20 plots, and the light zone seven plots.

Average height of cheatgrass was measured to the nearest whole centimeter to permit calculation of space occupied by fuel. The general level across the top of the cheatgrass was judged to be the average height. Occasional cheatgrass parts protruding above this level were excluded from the measurements.

All cheatgrass within each plot was carefully clipped, collected, and dissected into six component classes: stalks, leaves, peduncles, glumes, spikelets, and awns. A small amount of plant material, mostly spikelets without glumes, lay partially stuck in the soil and was left as litter. The material in each class was weighed and reduced to an ovendry basis using xylene distillation for determination of the moisture content (Buck and Hughes 1939).

Surface area and volume were measured for a randomly picked subsample of each component in the following manner: for stalks, peduncles, and awns, cross-sectional areas and perimeters were numerically integrated with length; for leaves and glumes, areas from blueprint outlines of flat surfaces were combined with particle thicknesses; for spikelets, both of these techniques were used (Brown 1968). These subsamples were also weighed.

Based upon these measurements, average volume per gram and surface area per gram factors were calculated for each component (table 1). These factors multiplied by total plot weights (grams) of each component yielded component volumes and surface areas that, when summed, gave total plot volume and surface area values. Porosity of each plot was then calculated from

$$\frac{\text{(Space occupied by fuel)} - \text{(Fuel volume)}}{\text{Fuel surface area}}$$

These values of porosity were subjected to linear regression analysis with weight per unit of ground area as the independent variable.

Table 1.--Volume per gram and surface area per gram factors for components of cheatgrass

Plant parts	Observations	Volume per gram	Surface Area per gram
		$cm.^3/g.$	$cm.^2/g.$
Stalks	880	2.80	211
Leaves	50	3.98	662
Peduncles	100	1.96	541
Spikelets	5	1.74	560
Awns	20	1.88	560
Glumes	9	2.31	1,652

RESULTS AND DISCUSSION

The regression in figure 1 shows that for the cheatgrass studied, which averaged 16 cm. in height, porosity can be precisely estimated from fuel weight. Fuel weight averaged 53.1 ovendry grams per square meter (474 lbs./acre), and porosity averaged 12.5 $cm.^3/cm.^2$. Porosity is closely associated with weight because cheatgrass grows as an upright plant. As weight increases, the grass of a given height becomes more dense, and porosity thereby decreases.

Height of cheatgrass varies according to location and weather conditions during the growing season (Klemmedson and Smith 1964). Height growth exceeding 60 cm. has been recorded following a warm, rainy fall and spring (Stewart and Hull 1949). For cheatgrass taller than that studied, which had a maximum height of 25 cm., particle sizes and amounts of space occupied by fuel would produce different regressions. Possibly only the Y intercepts would change for larger material. Investigation of fuel weight and porosity over the possible size range of cheatgrass, with height as an added variable, should provide a relationship that allows porosity to be estimated from fuel weight and height for all cheatgrass.

As porosity increases, air and gases can move more freely because the distance between particles is generally greater. This tends to favor rapid burning. However, the distance that radiant heat must travel between particles is also greater, and this hampers burning. Some value, or within some value range of porosity, fuel ventilation and heat-transfer distance are in optimum balance for maximum rate of fire spread.

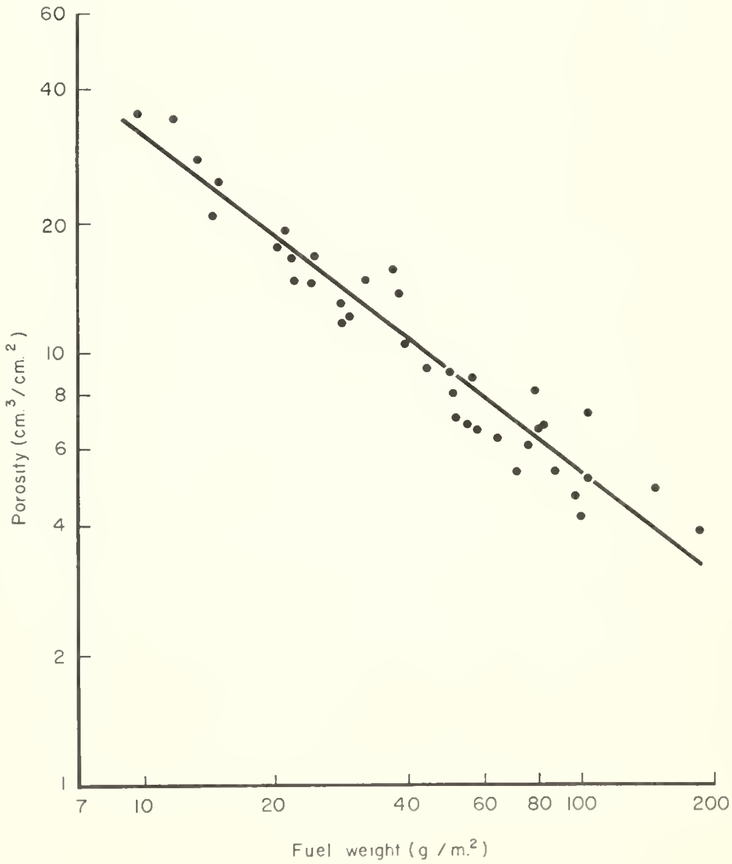


Figure 1.--Linear regression between fuel weight of cheatgrass and porosity. Log porosity = 2.2660 - 0.7706 (log weight) is the regression equation, significant at the 0.01 probability level, where r = 0.962 and standard error estimate equals 0.0710.

The precise relationship between porosity and flammability must be established before accurate evaluation of fire spread in cheatgrass is possible. Use of fuel weight (a variable related to forage production and easy to measure) to estimate porosity (a variable difficult to measure) is a practical aid in determining the flammability of cheatgrass. Estimation of porosity by this means could be a valuable step toward accurate evaluation of fire spread.

LITERATURE CITED

Barrows, J. S.
1951. Forest fires in the northern Rocky Mountains. U.S. Forest Serv., Northern Rocky Mountain Forest and Range Exp. Sta., Sta. Pap. 28, 251 pp.

Brown, J. K.
1968. Quantitative description of certain physical properties of ponderosa pine forest floor and cheatgrass fuels. Ph.D. Thesis, Univ. of Mich., 152 pp. Univ. Microfilms: Ann Arbor, Mich. (Diss. Abstr. 28B: 828).

Buck, C. C., and J. E. Hughes.
1939. The solvent distillation method for determining the moisture content of forest litter. J. Forest. 37(8): 645-651.

Hull, A. C.
1965. Cheatgrass--a persistent homesteader, U.S. Dep. Interior, Bur. Land Manage., Cheatgrass Symp. Proc. 1965: 20-26.

Klemmedson, J. O., and J. G. Smith.
1964. Cheatgrass (Bromus tectorum L.). Bot. Rev. April-June: 226-262.

Mutch, Robert W.
1967. Cheatgrass coloration--a key to flammability. J. Range Manage. 20(4): 259-260.

Stewart, G., and A. C. Hull.
1949. Cheatgrass (Bromus tectorum L.)--an ecologic intruder in southern Idaho. Ecology 30: 58-74.

Research Note

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

USDA Forest Service
Research Note INT-98

1969

COMPUTING PROCEDURE FOR GRAND FIR SITE EVALUATION AND PRODUCTIVITY ESTIMATION

Albert R. Stage[1]

ABSTRACT

Two subroutine programs to calculate productivity of grand fir sites from measurements of tree height, crown ratio, and age are described. A method for obtaining a graphical estimate of site quality is also provided when machine calculation is not appropriate. These procedures evaluate site on scales directly proportional to the potential of the site for growing grand fir. This potential is measured in units of cubic feet of the net current annual increment of the entire stand at the stage of development at which mean annual increment culminates.

A nonlinear, implicit expression for relative productivity (Q) of grand fir sites was introduced in a previous paper (Stage 1966) along with a procedure for rating productivity in cubic feet per acre per year. When relative productivity of the site is estimated from data for individual trees, there is considerable variation of these estimates due to the relative dominance of the trees within the stand. Much of this variation can be removed by adjustments based on the ratio of live crown to total height of the tree. The purpose of this Note is to provide computing algorithms to help forest managers evaluate site and productivity using these procedures.

The expression for relative productivity is

$$Q = b_1 \, (h^* - 4.5)^{b_2} \, (1 - e^{-b_3 Q(t+b_5)})^{b_4} \qquad (1)$$

in which

t = age at breast height in years
c = live crown length in percent of total height
h^*= total height in feet (h) adjusted for the departure of crown length from the standard crown percentage for a tree of this age.
$[\ln (h^* - 4.5) = \ln (h - 4.5) - 18.786 (\ln c - 3.747474 - 8.218305/t)/t]$

---

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

$b_1 = +3.368X10^{-5}$
$b_2 = +2.00$
$b_3 = +0.018167$
$b_4 = -4.00$
$b_5 = -2.70$

A listing of a FORTRAN subroutine to solve expression (1) is given in the Appendix. This program is derived from a general purpose program to solve general nonlinear equations, such as x = f(x) (Lance 1960; Wegstein 1960) and is executed by the statement

```
CALL RPGF (Q,H,T,C,IE)
```

in which the arguments are variables defined as follows:

Q = relative productivity as computed by RPGF
H = height in feet
T = age in rings at 4.5 feet above ground
C = live crown length in percent of total height
IE= an integer variable that should be zero on return from RPGF. Nonzero values of IE indicate one of several possible error conditions detected by RPGF. These error codes are listed in the Appendix.

Q can also be estimated from table 1 and figure 1. First, the total tree height is adjusted for crown ratio by the equation

$$h^* = (h - 4.5)\ (\text{multiplier from table 1}) + 4.5.$$

Then, Q can be read at the point corresponding to h* and age at breast height in figure 1 just as you use conventional site index curves.

Table 1.--Height multiplier for crown ratio adjustment in grand fir site evaluation

	Crown ratio								
Age	20	30	40	50	60	70	80	90	100
20			1.55	1.26	1.06	0.92	0.81	0.73	0.66
30	1.90	1.47	1.23	1.07	.96	.87	.80	.74	.69
40	1.57	1.30	1.13	1.02	.94	.87	.82	.77	.74
50	1.41	1.21	1.09	1.00	.93	.88	.84	.80	.77
60	1.32	1.16	1.06	.99	.94	.89	.86	.82	.80
70	1.26	1.13	1.04	.99	.94	.90	.87	.84	.82
80	1.22	1.11	1.04	.99	.94	.91	.88	.86	.84
90	1.19	1.10	1.03	.98	.95	.92	.89	.87	.85
100	1.17	1.08	1.03	.98	.95	.92	.90	.88	.86
110									
120	1.14	1.07	1.02	.99	.96	.93	.92	.90	.88
130									
140	1.11	1.06	1.02	.99	.96	.94	.93	.91	.90
150									
160	1.10	1.05	1.01	.99	.97	.95	.93	.92	.91
170									
180	1.09	1.04	1.01	.99	.97	.95	.94	.93	.92
190									
200	1.08	1.04	1.01	.99	.97	.96	.95	.94	.93

APPENDIX

Error Messages (IE)

The program RPGF will find a solution for most realistic combinations of height and age of dominant trees. However, the algorithm may fail as a result of errors in the tree data or poor selection of trees for site evaluation. If so, the variable IE will be nonzero on return from RPGF.

If IE is positive, then the 20 programed iterations were not sufficient to attain the level of precision specified in the accuracy test for termination. The solution may not be correct, even when less stringent accuracy criteria are applied.

If IE = -2, then the derivative of the growth function equaled zero for some trial estimate of Q. This condition could result from the starting values built into RPGF, or from accumulation of round-off errors in the machine arithmetic. (In the author's experience with data from several thousand trees, this error condition has never occurred.)

If IE = -3, several data-based errors may be at fault. A value for age of less than one is the most likely cause. Otherwise, the error condition might be due to unreasonable combinations of age and height that cause divergence of the algorithm.

Information for Programers

These programs use the following library routines:

ALOG(X)	= natural logarithm of X
DLOG(X)	= double precision version of ALOG(X)
EXP(X)	= exponential function of X
DEXP(X)	= double precision version of EXP(X)
DABS(X)	= absolute value of X, double precision.

Computers with floating point words longer than 32 bits would not require the double precision arithmetic that is used in the programs shown on page 3 and below. To convert to single precision, the names of the functions must be changed appropriately, the DOUBLE PRECISION statement removed, and the "D" changed to "E" in the exponent of the constants (e.g., instructions 91, 991, 1 and 5, below).

FORTRAN subroutine to calculate relative productivity

```
      SUBROUTINE RPGF( Q,H,T,CR,IER )
      DOUBLE PRECISION A,B,C,D,X,BT,DET,TOL,VAL,BRAC,ALGCR
      DIMENSION C(5)
      DATA C /-10.29862, 2.0, 0.018167, -2.7 , 2.0 /
      DIV = 0.5
      IER = 0
      ICT = 1
      COR = 0.
      I = 0
      BT =-C(3)*(T + C(4))
      IF ( T - 90. ) 91,91,92
   91 TOL = 1.0D0
      GO TO 95
   92 TOL = ALOG( 0.8*H/T )
   95 ALGCR = ALOG(H-4.5) - (ALOG(CR)-3.747474-8.218305/T)*18.786/T
```

(con. next page)

This subprogram is written as a function to be executed by a statement such as

PROD = CUPGF(Q)

in which the variable PROD will be assigned the value of the productivity computed by the function CUPGF using Q (from RPGF) for its argument.

The following tabulation shows estimates of productivity associated with values of Q from 0.6 to 1.5.

Q value	Productivity (Cu.ft./acre/year)
0.6	56
.7	67
.8	79
.9	91
1.0	105
1.1	118
1.2	133
1.3	149
1.4	166
1.5	184

REFERENCES

Lance, G. N.
1960. Numerical methods for high-speed computers. Iliffe, London. 166 pp.

Stage, A. R.
1966. Simultaneous derivation of site-curve and productivity rating procedures. Soc. Amer. Forest. Proc. 1966: 134-136.

Wegstein, J.
1960. Algorithm 2. Commun. Assoc. Comp. Mach. 3(2): 74.

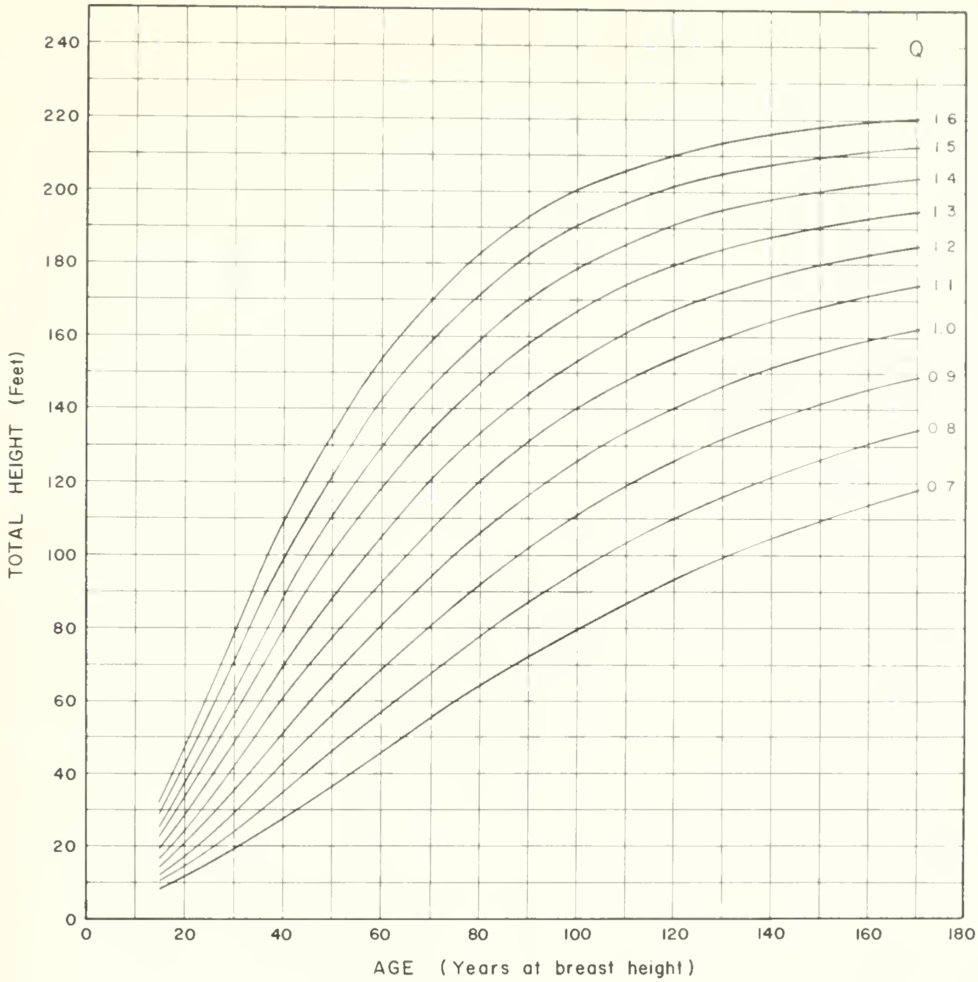


Figure 1.--Curves to estimate Q from height (adjusted for crown ratio) and age at breast height.

To convert Q, the estimate of relative productivity, to productivity in net cubic feet per acre per year requires an additional subprogram, the FORTRAN function given below:

```
FUNCTION CUPGF(S)
B = 89.761/S - 22.701
A = B *(0.5 + SQRT(0.25 + 12./(S*B)))
CUPGF = 22228.*EXP(-B/A)/(A + 12./S)
RETURN
END
```

```
   99 IF ( TOL .GT. 20.) GO TO 101
      DET = BT*DEXP( TOL )
      IF ( DET ) 991,100,100
  991 BRAC = 1.0D0 - DEXP(DET)
      IF (BRAC) 100,100,992
  992 TOL = C(1) + C(2)*(ALGCR - C(5)*DLOG(BRAC) )
      I = I + 1
  996 GO TO ( 21,22,23),IGT
   21 X = TOL
      A = X - TS
      B = -A
      IGT = 2
      GO TO 99
   22 VAL = X - TOL
C         START ITERATION LOOP
      IF ( VAL) 1,7,1
C         EQUATION IS NOT SATISFIED BY X
    1 B = B/VAL - 1.0D0
      IF(B) 2,8,2
C         ITERATION IS POSSIBLE
    2 A = A/B
      X = X + A
      B = VAL
      TOL = X
      IGT = 3
      GO TO 99
   23 VAL = X - TOL
C         TEST ON SATISFACTORY ACCURACY
      D = DABS(X)
      TOL = 0.0008*D
    4 IF ( DABS(A)-TOL) 5,5,6
    5 IF(DABS(VAL)-1.0D0*TOL) 7,7,6
    6 IF ( I - 20 ) 1,1,10
C         END OF ITERATION LOOP
    7 Q = DEXP(X)
      RETURN
C         ERROR RETURN IN CASE OF ZERO DIVISOR
    8 IER = -2
      RETURN
C         NO CONVERGENCE AFTER 20 ITERATION LOOPS. ERROR RETURN
   10 IER = I
      RETURN
C         ERROR CONDITION ON INITIAL ITERATION
   12 IER = -3
      RETURN
   14 IER = -4
      RETURN
  100 GO TO (12,12,102),IGT
  101 GO TO ( 14,14,102),IGT
  102 X = X - A
      A = DIV*A/B
      DIV = DIV*DIV
      I = I + 1
      GO TO 2
      END
```

Research Note

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

USDA Forest Service
Research Note INT-99 1969

USE OF SARAN SHADE CLOTH IN GREENHOUSE TO IMPROVE SUMMER SEEDLING GROWTH OF FIVE MOUNTAIN RANGE GRASSES AND FORBS

W. T. McDonough[1]

ABSTRACT

Seedlings of five range grasses and forbs--(Agastache urticifolia (Benth.) Kuntze), (Agropyron intermedium (Host) Beauv.), (Aquilegia caerulea), (Bromus inermis Leyss.), and (Rudbeckia occidentalis Nutt.)--were grown under experimental shade conditions in a greenhouse (located in Logan, Utah) during the summer. The seedlings were either unshaded or were under densities of 6, 20, 30, or 40 percent shade provided by saran shade cloth. Best growth generally was obtained by exposure to 6 percent shade, except for Aquilegia which responded more favorably at 20 percent shade; therefore, greenhouse shading of these densities is recommended for summer use to obtain satisfactory growth of these range plants, or those with similar shade requirements.

INTRODUCTION

Summer growth of plants in the greenhouse often is poor because of the excessive heating and desiccating effects of direct solar radiation. Although they aid in holding down leaf temperatures, the use of ventilating fans and water-cooled air conditioning systems is not entirely adequate for control of the excessive heating and desiccating effects that occur in a greenhouse during the warmer days of summer. In addition to fans and air conditioning, some type of artificial shading generally is a necessity for best growth of experimental plants under these conditions.

The older method of using whitewash or similar material on the outside glass of the greenhouse is sometimes unsatisfactory due to nonuniformity of application and the denseness of shading. Also, whitewash continues to provide shade during the fall and winter when shade may be detrimental to the growth of plants. A more desirable shading material would offer a choice of densities that are uniform in application and easily reproducible; furthermore, accessory equipment should be available to make the placement onto and removal from the greenhouse a quick and simple procedure. These desirable characteristics

[1]Plant Physiologist, stationed in Logan, Utah, at the Forestry Sciences Laboratory, maintained in cooperation with Utah State University.

can be readily obtained by use of Lumite[2] saran shade cloth (1). The cloth is a durable fabric woven from polyvinylidene chloride. A range of shades is provided by varying types and tightness of weaves.

There is information available concerning the use of saran shade cloth for optimum shading of certain horticultural species--ornamental trees, shrubs, and herbaceous flowering plants (1); however, such information is not available for species of the mountain rangeland. Therefore, experiments were directed toward providing such greenhouse shade information and determining if some degree of shade benefits the summer growth of mountain range plants under representative greenhouse conditions. The seedlings of five mountain range species were studied to determine their growth responses to four degrees of shade. It has been established that different species may vary greatly as to their shade requirements and shade tolerance (2,5); thus, no exact predictions can be made regarding the response of a particular species to any one degree of shade without experimental verification.

The seedling stage generally is considered to be more sensitive to heating and desiccating effects than are the later stages of development (4). Therefore, shade conditions suitable for the more critical seedling stage were assumed to be suitable for the mature plants.

METHODS AND MATERIALS

Seedlings of the five species (Agastache urticifolia (Benth.) Kuntze), (Agropyron intermedium (Host) Beauv.), (Aquilegia caerulea), (Bromus inermis Leyss.), and (Rudbeckia occidentalis Nutt.) were grown in the greenhouse in the unshaded condition and under Lumite shade cloth (Chicopee Mfg. Co.) with densities that provide 6, 20, 30, or 40 percent shade, i.e., reduce the total solar irradiance by these percentages. Seeds of the grasses were obtained from a commercial source and seeds of forbs were gathered from aspen rangeland in northern Utah. Seeds were planted at depths ranging from 1/4 to 1/2 inch in loam soil held in 5-pint plastic containers. Shading treatments were begun as soon as the seedlings emerged from the soil; then, within two weeks seedlings were thinned to four uniform plants per container.

Growth of the plants was evaluated by recording the weights of individual shoots that had been dried in an oven at 180°F. for 24 hours. These weight measurements were made after the seedling growth that occurred during the two-month period of July-August, 1968.

The experimental shading material consisted of 3- by 4-foot pieces of saran shade cloth which were positioned on horizontal wire supports at a height of 2-1/2 feet above the surface of the benches; there was no overlap of shading material. The arrangement of shading and plant containers was such that no direct solar radiation was received between 10 a.m. and 3 p.m. on any plants except those purposely exposed to full sunlight as a part of the experiment. During other daylight hours, plants under all treatments received the unobstructed oblique rays from the sun. At these times however, the total irradiance was low compared to mid-day conditions. Shading treatments were randomized on each of three benches, and there were two containers of seedlings of each species, for each shade density, and for each bench location. Containers within a given shading density and in a given location were rotated systematically twice weekly during the experiment. Plants received normal greenhouse care except for the experimental shading and were checked at regular intervals during the experiment for survival and signs of abnormal growth. Analyses of variance and studentized range tests (3) were used to evaluate the significance of differences in growth at the 5-percent level.

---

[2]The use of trade names herein is for identification only and does not necessarily imply endorsement by the USDA Forest Service.

Table 2.--Mean dry weight of shoots in mg. following two months of growth at different bench locations. Dry weights for each bench are averaged over the shading treatments of table 1.

Species	Bench		
	1	2	3
Agastache	(1) 258[a]	310[b]	231[c]
Agropyron	166[ab]	146[a]	174[b]
Aquilegia	98[a]	114[ab]	132[b]
Bromus	218[a]	231[a]	162[b]
Rudbeckia	244[a]	223[b]	253[a]

[1] Dry-weight values for any species having the same letter in superscript do not differ significantly at the 5-percent level.

DISCUSSION AND CONCLUSIONS

Light shading generally was advantageous for growth (table 1). For four of the species investigated, 6 percent shade appears to be a suitable compromise for use in Logan, Utah, and other localities where summer heat in the greenhouse adversely influences plant growth.

Aquilegia grew better when exposed to 20 percent shade. Undoubtedly, when studies require the growth of a number of species, special provisions will be necessary for those with specialized shade requirements; additional shade will be required over particular benches or portions of benches that hold species with greater shade requirements.

Bench location exerted an easily detectable effect on growth of seedlings otherwise shaded to the same degrees (table 2). This effect is attributable to a number of uncontrolled factors, including varying structural shading which was an unavoidable characteristic of the greenhouse structure and rate of air movement from place to place. The influence of bench location on growth should be considered in the planning of any greenhouse study.

RESULTS

By the end of the first five weeks of plant growth, mortality or abnormalities appeared in Aquilegia, Agastache, and Rudbeckia under particular treatments. Survival of Aquilegia was low in the unshaded condition. Furthermore, Agastache and Rudbeckia showed leaf burns around the margins and at the tips of the leaves in the unshaded condition, and there was evidence of chlorosis in Rudbeckia that was exposed to 40 percent shade.

The mean dry weight of shoots differed significantly in relation to the different densities of shade treatments (table 1) and bench location (table 2). Six percent of shade resulted in significantly better growth in Agastache and Agropyron; 20 percent shade was optimal for Aquilegia (table 1). For the remaining two species, the greater growth obtained at 6 percent shade failed to reach a significant level as compared to 0 and 20 percent for Bromus and 20 percent for Rudbeckia. No advantage was indicated by the light shading of Bromus although such light shade was not detrimental to growth. Shade at 6 percent and 20 percent was best for Rudbeckia.

Because only five of 24 seedlings of Aquilegia survived without shade, these data were not considered in the "0" percent shade analysis (table 1).

During the experiment, air temperatures in the greenhouse ranged from 94° to 61° F. (day and night), and relative humidities ranged from 32 to 78 percent. Solar irradiance on the predominantly clear days reached a maximum of 1.24 cal. $cm.^{-2}$ $min.^{-1}$. Air movement resulting from the fans ranged from less than 0.05 to 0.3 m.p.h. in different locations on the benches at seedling height. The greenhouse structure cast variable amounts of shade, depending upon time of day and location of the benches. These variations in air movement and shading may have been influential in the significant effect of bench location on growth (table 2).

Table 1.--Mean dry weight of shoots in mg. after two months of growth under the five shading treatments. Dry weights for each shading treatment are averaged over three benches.

Species	Shade (%)				
	0	6	20	30	40
Agastache	(1) 277[a]	323[b]	248[ac]	253[ac]	230[c]
Agropyron	176[a]	223[b]	171[a]	124[c]	115[c]
Aquilegia	(2) --	106[a]	143[b]	103[a]	107[a]
Bromus	210[ab]	231[a]	222[ab]	193[bc]	162[c]
Rudbeckia	211[a]	294[b]	268[bc]	239[ac]	187[a]

[1]Dry-weight values for any species having the same letter in superscript do not differ significantly at the 5-percent level.
[2]Data not included in analysis.

The experiment was conducted in a Lord and Burnham "Blue Ribbon Century" greenhouse, equipped with ventilating fans and a water-cooled air conditioning system. The cooling system is a water-curtain type in which the water trickles through a mat of fibers. This mat is 18 feet in total length (in two sections--see figure 1), 4 feet high, and 1 inch thick. Air temperature and humidity within the greenhouse were recorded on a hygrothermograph, solar irradiance with a Belfort pyrheliograph, and velocity of air movement at a height of 6 inches above the benches with a Hastings air-meter. The accuracy of the manufacturer's percentage shade designations for each density of saran shade cloth was confirmed by measuring the solar irradiance under the unshaded and each of the shaded conditions with a Kettering radiometer.

In the greenhouse, three 5- by 14-foot benches were oriented with their longer dimensions paralleling a north-south line (figure 1). The air conditioning system and three 18-inch fans were located on the east and west walls respectively, and were in operation during the day when air temperatures exceeded 70° F. The longitudinal center line of bench number 1 was located approximately 8-1/2 feet from the cooling system on the east wall. Bench number 3 was located a similar distance from the west wall. The center bench (number 2) was separated from the adjacent benches by walkways that were 2-1/2 feet in width.

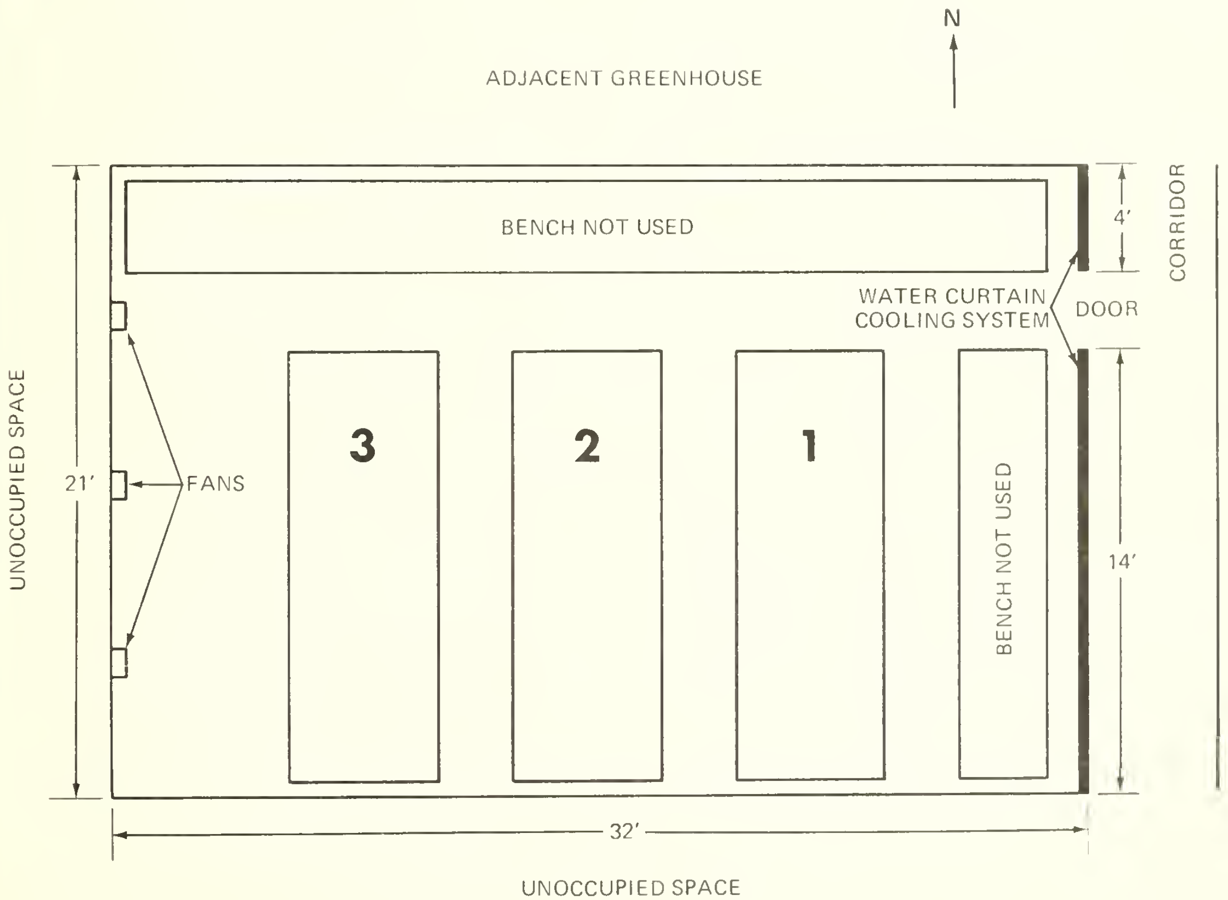


Figure 1.--Greenhouse plan showing the three benches (1, 2, and 3) upon which the experimental plants were grown.

LITERATURE CITED

1. Anonymous
   1967. Lumite saran shade cloth--perfect greenhouse shading. AAA Tent and Awning Company, Salt Lake City, Utah.

2. Daubenmire, R. F.
   1959. Plants and Environment. New York: John Wiley and Sons.

3. Goldstein, A.
   1964. Biostatistics. New York: The MacMillan Company.

4. Langridge, J. and J. R. McWilliam
   1967. Heat responses of higher plants. Pp. 231-292, _in_ Thermobiology, A. H. Rose (ed.). New York: Academic Press.

5. Talling, J. F.
   1961. Photosynthesis under natural conditions. Ann. Rev. Plant Physiol. 12: 133-154.

Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN, UTAH 84401

USDA Forest Service
Research Note INT-100

1969

EFFICIENCY OF THREE DATA-GATHERING METHODS FOR STUDY OF LOG-MAKING ACTIVITIES

Rulon B. Gardner and Paul L. Schillings[1]

ABSTRACT

Three data-gathering methods — continuous reading, work sampling, and time-lapse photography — were used for accumulating log-making information. Using the estimates from the continuous reading method as the standard, work sampling offered economy at no sacrifice in accuracy for giving an unbiased breakdown of daily work time into felling, limbing and bucking, extra buck cuts, and travel plus unproductive time. When travel and unproductive time were considered separate elements, continuous reading provided the only unbiased estimates.

The objective of this study was to evaluate the efficiency of two data-gathering methods — work sampling and time-lapse photography — for studying the daily activities of sawyers. A third method — continuous reading — was used to obtain data to use in evaluating the aforementioned methods because continuous reading is assumed to reveal dependable values even though it might not be the most economical method.

The work sampling method used involved random observations. Another type of work sampling, in which observations are made on a systematically distributed basis, was considered. However, we rejected it because of the danger of reaching false conclusions if the sawyer's activities shifted into phase with the predetermined intervals. Furthermore, it was rejected because the predetermined sample interval would have had to be sufficiently small to provide at least one observation from each of the four activities studied: (1) felling; (2) limbing and bucking; (3) travel from tree to tree; and (4) extra bucking cuts because of defects.

Continuous filming, which is another type of photographic method, was rejected because of the high cost involved. All of the methods considered are probably among the methods most widely used in logging studies; however,

---

[1] *Research Engineer in charge of Station's Engineering Systems and Steep Mountain Forestry Work Unit, and Research Engineer, respectively, stationed at the Forestry Sciences Laboratory in Bozeman, which is maintained in cooperation with Montana State University.*

we recognize other sampling methods are available, such as those described by Ferber[2] and Madow.[3]

We were particularly interested in testing the time-lapse photography method because it has won widespread use in production-line industries and offers the following advantages: (1) it provides permanent proportional-time records for observing methods, work patterns, safety practices, and worker distributions when the activities can be delineated; (2) it requires less training of those charged with gathering the data; and (3) it is not as tedious.

STUDY METHODS

The data were gathered at two logging locations on the Gallatin National Forest in Montana — Wild Horse Creek and East Fork Hyalite Creek. Our crews took data for three complete workdays at the Wild Horse Creek site and then gathered data on the fourth day on the East Fork Hyalite Creek site.

We assigned two men to taking continuous readings and one man each to the work sampling and time-lapse photography. The continuous reading method required two observers because one observer could not work the stopwatches, record the times, and dodge snags and falling trees all at the same time.

Continuous Reading

All activities of the sawyer were accounted for in minutes and fractions of minutes. Immediately after a sawyer stopped one activity and began another, the elapsed time of the first activity was recorded. They proceeded as follows: Observer 1 started time on watch 1; at the instant sawyer activity changed, he simultaneously stopped watch 1 and started watch 2. Stopwatch 1 was read, reset to zero, and the time called to observer 2. Observer 2 noted the activity in progress for that time and recorded the time under the proper activity.

Observer 1 was told that if he ever punched both watches before a true change in activities became obvious, he was to note immediately the time on the stopped watch, reset it to zero, and when certain of an activity change, punch both watches, thus stopping one and starting the other, as explained above. The correct activity time in this case would be the noted time plus the time on the watch just stopped. Fortunately, this type of error did not turn up. At the end of the day, the total time for each activity was adjusted to a percent of total daily time. For instance, on the first day operations were studied, the total time spent felling amounted to 55.18 minutes, while the total time on the job less lunch breaks was 427 minutes; hence, the percent of time spent felling was 12.92 (see table 1).

Work Sampling[4]

By studying figure 1, it is easy to obtain a clear idea of how our observer recorded his observations. The two digits following each minute represent seconds. These were changed for each of the 4 days on which we gathered data. The changes were selected at random, based upon a random timetable published by Lambrou.[5]

The observer determined a sawyer's activity at precisely the indicated number of seconds past a minute, and recorded the proper activity code letter next to that minute. For example, on the first study day at 15 seconds past 0923, the observer spotted the sawyer in the act of felling. (After recording the letter "F," the observer saw that he had to be alert for the next observation at 55 seconds past 0924.)

---

[2] *Ferber, Robert. Market research. 542 pp., illus. New York: McGraw-Hill Book Co., Inc. 1949.*

[3] *Madow, L. H. Systematic sampling and its relation to other sample designs. J. Amer. Statist. Assoc. 41(234): 204-217. 1946.*

[4] *For more information on this method, see Barnes, Ralph M. Work sampling. 2d Ed., 283 pp. New York: John Wiley & Sons. 1957.*

[5] *Lambrou, F. H. Guide to work sampling, part IV. 106 pp., illus. New York: John F. Rider Publ., Inc. 1962.*

Table 1. — Confidence limits for estimates of time devoted to log-making activities using work sampling and time-lapse photography methods of data gathering[1]

(In percent of daily work time)

Study day	Activity	Continuous reading[2]	Work Sampling			Time-lapse photography		
		Mean estimate	Mean estimate	Lower limit	Upper limit	Mean estimate	Lower limit	Upper limit
1	Felling	12.92	13.81	10.54	17.08	13.34	12.02	14.66
	Limbing and bucking	37.38	36.07	31.51	40.62	45.67	43.74	47.60
	Travel, tree to tree	6.44	14.99	11.60	18.38	7.96	6.91	9.01
	Extra buck cuts	1.29	1.87	0.58	3.15	0.71	0.38	1.03
	Unproductive	41.97	33.26	28.79	37.73	32.32	30.51	34.13
		100.00	100.00			100.00		
2	Felling	17.51	18.85	15.17	22.53	11.03	9.83	12.23
	Limbing and bucking	42.21	40.46	35.85	45.07	28.74	27.00	30.48
	Travel, tree to tree	5.21	12.18	9.11	15.25	11.03	9.83	12.23
	Extra buck cuts	0.51	0.69	−0.09	1.47	1.15	0.74	1.56
	Unproductive	34.56	27.82	23.61	32.03	48.05	46.13	49.97
		100.00	100.00			100.00		
3	Felling	12.53	13.54	10.21	16.87	13.79	12.42	15.16
	Limbing and bucking	31.92	30.79	26.30	35.28	35.96	34.05	37.86
	Travel, tree to tree	3.90	9.11	6.31	11.91	4.43	3.61	5.25
	Extra buck cuts	1.14	1.73	0.46	3.00	0.49	0.21	0.77
	Unproductive	50.51	44.83	39.99	49.67	45.33	43.35	47.31
		100.00	100.00			100.00		
4	Felling	9.62	10.25	7.41	13.09	11.16	9.96	12.36
	Limbing and bucking	28.97	27.79	23.60	31.98	34.85	33.03	36.67
	Travel, tree to tree	3.12	7.29	4.86	9.72	8.65	7.58	9.72
	Extra buck cuts	3.02	4.32	2.42	6.22	6.84	5.88	7.80
	Unproductive	55.27	50.35	45.67	55.03	38.50	36.64	40.36
		100.00	100.00			100.00		

[1] *Confidence limits were determined using the mathematical expression shown under "Results and Discussion" and can be expected to be correct 95 percent of the time.*

[2] *As explained in the text, the estimated means derived using the continuous reading method were used as a standard for judging the accuracy of estimated means derived using the other two methods.*

The work sampling method proved unreliable for recording travel from tree to tree, which in turn affected recording of unproductive times. At a glance, an observer knew whether the activity performed was felling, limbing and bucking, or extra bucking because of defect. However, he could not always be certain whether a walking sawyer was productive or unproductive, because any instantaneous observation of a walking sawyer introduced one of three possibilities: (1) he is returning to a tree butt to begin bucking; (2) he is walking to his fuel cans or a resting place; or (3) he is walking to the next tree to fell it. To fulfill the requirement of recording instantaneous random observations, it was impossible for the observer to delay long enough to be certain of a sawyer's activity without introducing excessive bias.

Therefore, the work sampling method offers economy at no sacrifice in accuracy for estimating the breakdown of daily work time into felling, limbing and bucking, extra buck cuts, and travel plus unproductive activities. But where travel and unproductive times must be separated, continuous reading provides the only unbiased measurements.

In retrospect, we feel that the systematic predetermined interval type of work sampling would have provided accurate estimates and recommend consideration of its use in similar studies.

Figure 1. — Sample of daily observation sheet. On an actual sheet, 1-minute intervals are listed for 11 hours. This sample was shortened for reproduction purposes; three dots (. . .) indicate intervening time.

STUDY:				SAWYER:		
AREA:				DATE:		
0700-00-	0923-15-F	1120-05-	1355-35-L	1414-00-F	1515-50-	1711-05-L
0701-40-	0924-55-L	1121-20-	1356-10-L	1415-50-U	. . .	1712-35-U
0702-15-	0925-50-L	. . .	1357-50-U	1416-10-L	1526-05-	1713-15-
0703-00-	0926-50-U	1130-10-	1358-15-	1417-30-L	1527-05-	1714-20-
0704-25-	. . .	1131-35-	1359-05-	. . .	1528-55-B	. . .
. . .	1115-25-T	1132-25-T	1400-30-	1510-00-L	1529-35-L	1800-00-
0919-05-	1116-40-U	1133-25-L	1401-25-	1511-55-U	1530-20-L	
0920-30-	1117-10-F	1134-40-B	. . .	1512-15-F	. . .	
0921-45-F	1118-30-	1135-20-L	1412-20-	1513-30-	1709-05-T	
0922-00-F	1119-15-	. . .	1413-55-	1514-35-	1710-50-F	

-ACTIVITY CODING-

F - Felling
L - Limbing and Bucking
T - Travel from Tree to Tree
B - Extra Buck Cuts because of Defect
U - Unproductive Time

Observations were taken at some point within each minute except during lunch breaks. Notice on figure 1 that recording began at 0921 and stopped at 1118, when the sawyer ate a sandwich. He resumed work at 1132, not stopping again until 1358 for more of his lunch. His next work span was from 1414 to 1513, and his final one from 1528 until he chose to quit at 1713. This gave a total number of 427 code letters for the first day.

Each group of code letters was totaled at the end of the day and the activity corresponding to the code letters was adjusted to a percent of the total daily code letters.

Time-Lapse Photography

Our observer used a camera that could be operated at lapses between frame exposures ranging from 1 to 120 seconds. We chose the 10-second interval because it permitted us to collect a maximum of observations on each roll of film for the longest workday expected.

When the continuous reading and work sampling began, the observer switched on a battery-powered exposure device that automatically snapped a picture every 10 seconds. During the rest of the day, he merely repositioned the camera and adjusted its lens settings.

After the film was developed, activities shown on the frames were counted for each category of activity. For instance, 342 frames were counted for felling out of a total of 2,562 frames for the first study day.

RESULTS AND DISCUSSION

Confidence limits were established at the 5-percent level for the estimates derived from the work sampling and time-lapse photography methods. These confidence limits are shown in table 1 and were computed as follows:

$$p-1.96\phi \leqslant P \leqslant p+1.96\phi,$$

where

$\phi = \sqrt{\frac{p(1-p)}{N}}$, the standard error for the sample estimate of proportions

p = ratio of the number of observations for each activity to the total daily observations for all activities, or proportion of workday by activity

P = ratio of continuous reading times to total daily times

N = total number of daily observations.

When the estimate of the mean for continuous reading didn't fall within the corresponding confidence limits, the corresponding sample mean derived from either the work sample or time-lapse photography methods was considered to contain bias. The estimates of the means derived from the continuous reading method were considered, of course, to be without bias for all activities. The percentage of the workdays on which apparent bias was absent is shown in the following tabulation:

Activity	*Work sampling*	*Time-lapse photography*
Felling	100	50
Limbing and bucking	100	0
Travel, tree to tree	0	25
Extra buck cuts	100	0
Unproductive	0	0

The presence of apparent bias for any of the 4 observation days suggests that the estimating method contains objectionable inaccuracies.

CONCLUSIONS

The time-lapse photography method proved to be unacceptable because it was difficult to delineate the activities in the pictures. Undergrowth and slash obscured over 55 percent of the observations. The observers were forced to keep continually on the move, either to stay in the range of the sawyer's activities or to retreat from falling trees and snags. Such movements in and out of shadows forced frequent adjustments to be made in lens settings, and these adjustments were often forgotten. Thus, we were able to make only "best estimates" about a sawyer's activities in over half of the pictures taken.