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U.S.D.A. FOREST SERVIC
RESEARCH NOTE RM-151

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S. DEPARTMENT OF AGRICULTURE

CKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATI

Influence of Antitranspirants[1] on Water Use, Growth Characteristics, and Relative Drought Resistance of Ponderosa Pine Seedlings

W. J. Rietveld and L. J. Heidmann[2]

Ponderosa pine seedlings were treated with foliar sprays of Cycocel, hexadecanol, and Foli-gard at age 2 months, and were grown under favorable conditions in a controlled environment chamber. Cycocel significantly improved water use efficiency when soil moisture was optimal, but had no effect when moisture was limiting. In certain instances, height growth was stimulated by the hexadecanol and Foli-gard treatments. Limiting soil moisture alone produced greater resistance to moisture loss than any of the antitranspirant treatments.

In the Southwest, spring-planted ponderosa pines (Pinus ponderosa Laws.) are confronted with an annual spring drought lasting 2 months or longer. During this period, lack of adequate moisture and excessive transpiration create water stresses within the seedlings that limit survival and growth. A possible way to alleviate these stresses is to reduce transpiration with antitranspirants.

According to Gale and Hagan (1966), antitranspirants may be classified as materials that: (1) cause stomatal closure, (2) form thin films, (3) form thick films, or (4) retard growth or reflect light. Thick surface films tried on conifers have generally produced inconsistent results (Shirley and Mueli 1938, Thames 1961). Failures with these heavy, wax-based foliage coatings are attributable to an unfavorable upset of the heat balance in needles (Thames 1961), and to interference with plant mineral nutrition (Gale and Hagan 1966).

In recent years, long-chain alcohols such as hexadecanol, which form a monomolecular film on the leaf surface, have been tested. This film is highly impermeable to water vapor. Stoeckeler (1966) applied hexadecanol as a foliage dip to red pine (Pinus resinosa Ait.) seedlings prior to planting on a droughty site, and reported an 18.4-percent gain

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[1] *Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

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in survival of treated seedlings. He found no difference in first-year survival on a more favorable site.

Foli-gard, a water-soluble polymer that forms a thin, clear, flexible film on foliage, was tested on planted Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings (Roy 1966.) Although the treatment did not affect seedling survival, mean height of treated seedlings was significantly greater.

Certain growth retardants such as phosfon and Cycocel have been reported to reduce plant water stress and the transpiration/growth ratio (total transpiration divided by total dry matter production) (Goodin et al. 1966, Halevy and Kessler 1963). Plants treated with Cycocel reportedly require less water, are more resistant to wilt (Halevy and Kessler 1963), heat (Cathey 1962), salt (Marth and Frank 1961), and frost (Marth 1965).

This experiment was designed to evaluate the effects of hexadecanol,[3] Foli-gard,[4] and Cycocel[5] on growth, transpiration, and drought resistance of young ponderosa pines grown under two moisture regimes in a controlled environment chamber.

Materials and Methods

The experiment was conducted in two concurrent phases; each phase consisted of 32 pots that contained 12 seedlings each. The experimental design was a 4x2 factorial (three antitranspirants + control x two soil moisture levels) arranged in a completely randomized design with four replications. In phase A, the objectives were to determine the effects of antitranspirants on water use and growth characteristics; in phase B the effects upon relative drought resistance and the capacity of the seedlings to resist moisture loss were evaluated.

Metal pots, 4.5 inches in diameter by 12 inches high, were filled with equal weights of screened, air-dry forest soil (a silt loam derived from limestone, A horizon, 0-6 inches). The soil surface was covered with a thin layer of Perlite to lessen evaporation and damping-off. Each pot was planted with 12 newly germinated ponderosa pine seedlings which were then raised in a growth chamber under a constant optimum temperature of 23° C. (Larson 1967) and 16-hour photoperiod for 58 days. The antitranspirants tested, as aqueous foliar sprays were:

	Percent in water	Number of applications
Hexadecanol	1	1
Foli-gard	20	1
Cycocel + Tween 40[6]	0.25+0.025	4, biweekly

Two regimes of soil moisture, 10-15 and 25-30 percent of ovendry weight, designated as "low" and "high" soil moisture, respectively, were begun concurrently with the antitranspirant treatments. Soil moisture was maintained within these ranges by pot weight, and water use was recorded. Concurrently, evaporative water loss from eight pots without seedlings was recorded to determine the weight of water transpired. Four accessory pots of seedlings were harvested at 58 days so that mean seedling dry matter production during the 82-day period following treatment could be determined. After 140 days, foliage height (distance from cotyledons to shoot tip) and dry weight of tops and roots were determined. Data on foliage height, mean top dry weight, mean root dry weight, top/root ratio, mean dry matter production, mean transpiration per seedling (after treatment), and transpiration/growth ratio were analyzed by analysis of variance.

After phase A was terminated, seedling resistance to moisture loss and relative drought resistance were tested with the identically treated phase B seedlings. The seedlings were watered to their designated soil moisture level the day before the drought tests began. Then each pot of seedlings was thinned so that at least two seedlings were removed from each pot, and all pots contained the same

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[3] *ADOL 52-NF was supplied by the Archer Daniels Midland Company.*

[4] *Rutex Foli-gard is manufactured by the UBS Chemical Company.*

[5] *Cycocel, technical grade (98 percent active ingredient) was furnished by the American Cyanamid Company.*

[6] *Tween 40 was used in preference to Tween 20 because of its lack of biological activity (Vieitez et al. 1965).*

number of seedlings. The two seedlings removed from each pot were tested for their capacity to resist moisture loss (Sullivan and Levitt 1959) by determining the decline in foliage moisture content (FMC, percent moisture content based on ovendry weight). The residual seedlings were subjected to an artificial drought; relative drought resistance was determined by rewatering one pot from each treatment combination after 10, 20, 30, and 40 days without water.

Results and Discussion

Phase A

Table 1 presents the mean foliage height, mean top and root dry weight, and top/root ratio for each of the treatments under both soil moisture levels. The effects of the antitranspirants and soil moisture on transpiration per seedling, dry matter production, and transpiration/growth ratio are presented in table 2. All growth and moisture-use values for seedlings grown with high soil moisture were significantly greater than those for low soil moisture except the top/root ratio, which was significantly higher for seedlings grown under low soil moisture. This result disagrees with the findings of Steinbrenner and Rediske (1964), who reported that high soil moisture increased the top/root ratio. The difference is traceable to the effects on root weight. Steinbrenner and Rediske found little difference in root weight between high and low soil moisture, whereas in the present study high soil moisture increased root weight.

Cycocel did not affect foliage height or dry weight significantly. With high soil moisture, Cycocel significantly reduced transpiration per seedling and the transpiration/growth ratio, which implies improved water use efficiency. Under low soil moisture, however, where efficient water use may be critical, the Cycocel-treated seedlings did not differ significantly from the control seedlings.

Hexadecanol had no significant effects on water use. Although treatment with hexadecanol with high soil moisture significantly increased foliage height, the actual increase was small and may not be of practical importance. Under low soil moisture, stimulation of height growth was probably overcome by the growth-suppressing influence of water stress. Abdalla and Flocker (1963) and Roberts and Lage (1965) report large increases in weight of treated plants. Long-chain primary alcohols with plant-growth-promoting activity have been isolated from Maryland mammoth tobacco (Vlitos and Crosby 1959). Hexadecanol is more commonly reported to reduce plant growth than to stimulate it, however.

Foli-gard increased the height of treated seedlings significantly under the low soil moisture regime. The greater height growth was accompanied by moderate, but not significantly greater, top dry weight. There were no significant effects on the top/root ratio. Similarly, in work with Douglas-fir, Roy (1966) found that treatment did not affect seedling survival, but apparently promoted height growth. Treatment with Foli-gard did not affect water use.

Phase B

The FMC critical for survival of ponderosa pine seedlings is approximately 100 percent,[7] but this value depends on the exact nature of the desiccating environment. Below this critical value, the effects of the antitranspirants on FMC have little meaning in terms of seedling survival from drought. Treatment differences in resistance to moisture loss were therefore evaluated in terms of the time to reach 100 percent FMC (fig. 1).

At the time the seedlings were severed there was no difference in FMC between the two soil moisture levels. After they were severed, however, seedlings grown under low soil moisture required significantly more time to reach 100 percent FMC. The actual difference was 1.4 days. This implies that soil moisture pretreatment had some effect on seedling resistance to loss of moisture.

The antitranspirants influenced the rate of desiccation, but not in a fashion that would improve survival. When the seedlings were severed (day 0), the Cycocel-treated plants grown under both levels of soil moisture had a higher FMC than the controls,

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[7] *Personal communication with Dr. M. M. Larson, Ohio Agricultural Research and Development Center, Wooster, Ohio.*

Table 1.--Effects of antitranspirants and soil moisture on growth characteristics of ponderosa pine seedlings (values listed are treatment means)

Treatment	Foliage height		Mean top dry weight		Mean root dry weight		Top/root ratio	
	High	Low	High	Low	High	Low	High	Low
	Inches		- - - -	- Grams -	- - - -			
Cycocel	1.15	0.80	0.69	0.52	0.49	0.21	1.41	2.48
Hexadecanol	1.35**	.86	.90	.53	.39	.15	2.31	3.53
Foli-gard	1.25	.97*	.90	.62	.30	.20	3.00	3.10
Control	1.14	.82	.77	.51	.40	.18	1.93	2.83

* Significantly different from control at the 5 percent level.
** Significantly different from control at the 1 percent level.

Table 2.--Effects of antitranspirants and soil moisture on water use by ponderosa pine seedlings (values listed are treatment means)

Treatment	Transpiration per seedling (water)		Dry matter production[1]		Transpiration/growth ratio	
	High	Low	High	Low	High	Low
	- - - -	- Grams -	- - - -			
Cycocel	352.6**	215.0	0.96	0.51	367.3*	421.6
Hexadecanol	448.5	220.9	1.07	.47	419.2	470.6
Foli-gard	457.5	232.9	.98	.59	466.8	394.8
Control	465.9	210.3	.94	.47	495.6	447.5

[1] Dry matter formed during the 82 days following treatment.
* Significantly different from control at the 5 percent level.
** Significantly different from control at the 1 percent level.

as did the hexadecanol-treated plants under low soil moisture. During the desiccation period, these treated seedlings exhibited lower FMC than the controls and required significantly fewer days to reach 100 percent FMC (fig. 1). Thus, the Cycocel and hexadecanol treatments apparently lowered seedling resistance to moisture loss. Low soil moisture pretreatment had a greater effect on resistance to moisture loss of severed seedling tops than did any of the antitranspirants.

The test for relative drought resistance was unsuccessful because most of the seedlings recovered. Some seedlings died after 40 days of drought, but the results were inconclusive. During the drought test, the soil moisture content dropped 1 to 2 percent below the 15-atmosphere moisture percentage.

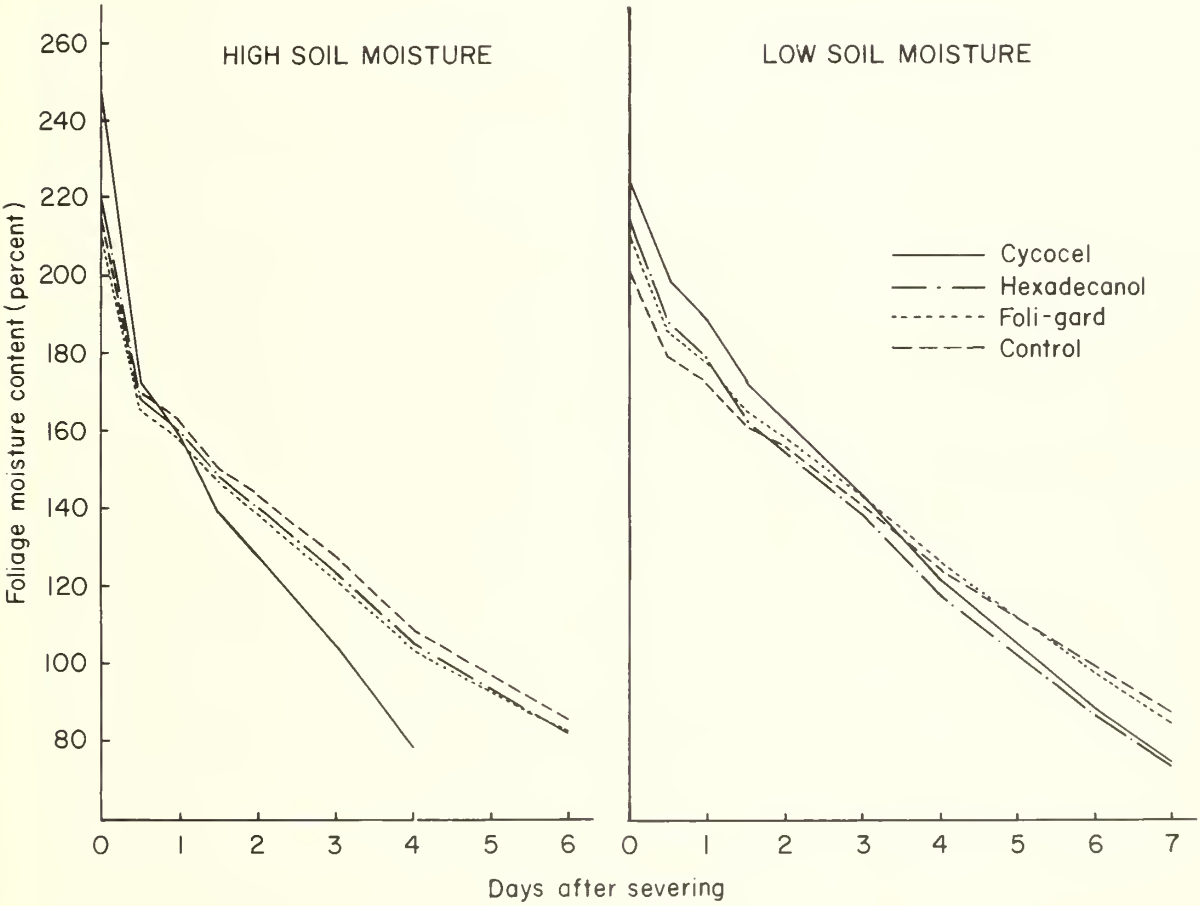

Figure 1.--Foliage moisture content (FMC) of severed tops of treated seedlings during a desiccation period in the growth chamber. Each line represents the average of eight seedlings.

Summary and Conclusions

Principal results of the study are:

1. Seedlings grown under high soil moisture (25-30 percent of ovendry weight) grew taller and heavier, had a lower top/root ratio, and used more water with less efficiency than seedlings grown under low soil moisture (10-15 percent of ovendry weight).
2. Treatment with Cycocel reduced transpiration and therefore increased water-use efficiency only in seedlings grown under high soil moisture. Hexadecanol stimulated height growth in seedlings grown under high soil moisture, whereas Foli-gard stimulated height growth only in seedlings grown under low soil moisture.
3. Seedlings grown under low soil moisture lost moisture more slowly after they were severed than seedlings grown under high soil moisture. Seedlings treated with Cycocel or hexadecanol maintained a higher FMC than the controls while growing under low soil moisture, but lost moisture more rapidly than the controls when severed from their root systems. Foli-gard had no effect on seedling resistance to moisture loss.
4. The tests of antitranspirants and soil moisture on relative drought resistance were inconclusive.

The following conclusions can be drawn:

1. Low soil moisture alone enhanced seedling resistance to moisture loss more than any of the antitranspirant treatments. Under the conditions of the experiment, none of the antitranspirants had any effect on water economy under low soil moisture. Cycocel and hexadecanol apparently reduced seedling resistance to moisture loss. Therefore, it is doubtful if any of the antitranspirants as applied in this experiment would significantly improve seedling resistance to drought.
2. Both hexadecanol and Foli-gard significantly increased seedling growth. The actual differences in seedling height were small. Growth stimulation by hexadecanol appeared to be overcome by moisture stress, but stimulation by Foli-gard was not.

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U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM-152

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Measuring Angles With a Carpenter's Folding Ruler

M. Martinelli, Jr., and R. A. Schmidt, Jr.[1]

A table is given that permits marking 6-foot and 2-meter folding rulers so they can be used to measure angles directly. Accuracy varies from 2-1/2 to 5 degrees.

Have you ever needed a quick, handy way to measure angles in the field? Take time to mark a carpenter's folding ruler as described below and you will have an easy-to-use, portable tool. Table 1 gives the position of the "zero end" of a 6-foot ruler and of a 2-meter ruler for selected values of angle A and angle B (fig. 1).

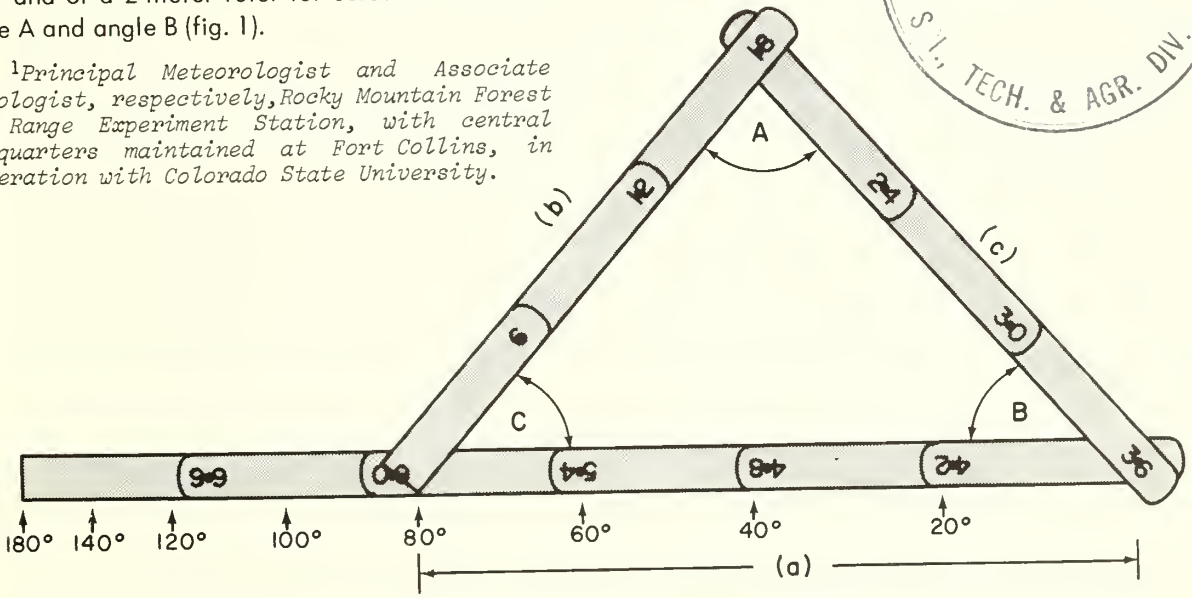

Figure 1.--A carpenter's folding ruler, folded to measure angles. The degree markings, a few of which are shown below the ruler, should be lettered directly on the ruler at the positions given in table 1. The value of angle A is read directly from the zero end of the marked ruler. The value of angle B (or C) can be calculated quickly. In this illustration, angle A is 80°, and angle B (or C) is $\frac{180° - A}{2}$ *or 50°.*

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How to Mark Ruler

Fold the ruler into an isosceles triangle (fig. 1) with the folds at 18 and 36 inches for a 6-foot ruler and at 50 and 100 cm. for a 2-meter ruler. Now mark the base of the triangle according to the values given in table 1. If the ruler will be used mostly to measure angles in the horizontal plane, use angle A values; if it will be used mostly for angles in the vertical plane, use angle B values. For example, on a 6-foot ruler to be used mostly for horizontal angles, the 10° mark will be at 39-1/8 inches; the 20° mark at 42-3/16 inches; and so forth. On a 2-meter ruler also marked for angle A, the 10° mark will be at 108.7 cm.; the 20° mark at 117.4 cm.

Markings can be made with paint, waterproof ink, or decals covered with plastic spray. A combination of numbers and symbols such as diamonds, dots, or arrows is probably most legible. The new markings will be easy to distinguish because the regular inch or cm. numbers appear upside down when the ruler is used to measure angles.

How to Measure Angles

For most horizontal angles, the ruler can be adjusted so angle A (fig. 1) matches the angle to be measured. The size of angle A can then be read directly from the "zero end" of the marked ruler. For many vertical angles, it may be more convenient to adjust the ruler so angle B matches the angle to be measured. In this case it is possible to read the value of angle A as before and then calculate B from the formula,

$$B = \frac{180^\circ - A}{2}$$

which is based on the fact that A + B + C = 180° for any triangle and that B and C are equal for an isosceles triangle.

If the ruler is used mostly for vertical angles, it may be more convenient to mark it with angle B rather than angle A values. In this case, a 6-foot ruler would have the 85° mark at 39-1/8 inches, the 80° mark at 42-3/16 inches, and so forth from columns 2 and 6 of table 1.

Table 1.--Data needed to mark a folding ruler so it can be used to measure angles (values computed from the formula $\sin \frac{A}{2} = \frac{a/2}{b}$ (see fig. 1) when b and c = 18 inches for a 6-foot ruler and 50 cm. for a 2-meter ruler)

Angle (degrees)		Position of "zero end"		Angle (degrees)		Position of "zero end"	
A	B	6-foot ruler	2-meter ruler	A	B	6-foot ruler	2-meter ruler
		Inches	Cm.			Inches	Cm.
10	85	39-1/8	108.7	90	45	61-1/2	170.7
15		40-11/16	113.1	95		62-1/2	173.7
20	80	42-3/16	117.4	100	40	63-5/8	176.6
25		43-13/16	121.6	105		64-5/8	179.3
30	75	45-5/16	125.9	110	35	65-1/2	181.9
35		46-13/16	130.1	115		66-3/8	184.3
40	70	48-5/8	134.2	120	30	67-3/16	186.6
45		49-13/16	138.3	125		67-7/8	188.7
50	65	51-3/16	142.3	130	25	68-5/8	190.6
55		52-5/8	146.2	135		69-5/16	192.4
60	60	54	150.0	140	20	69-13/16	194.0
65		55-5/16	153.7	145		70-5/16	195.4
70	55	56-7/8	157.4	150	15	70-13/16	196.6
75		57-7/8	160.9	155		71-1/8	197.6
80	50	59-1/8	164.3	160	10	71-1/2	198.5
85		60-5/16	167.6	165		71-11/16	199.1
				170	5	71-7/8	199.6

U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM-153

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Pot Tests Indicate Fertilizers Can Improve Soils From Black Mesa In Western Colorado

W. M. Johnson[1]

Greenhouse tests of the nutritive status of soils from Black Mesa in western Colorado indicate that production of herbage can be increased by use of fertilizers. A combination of 100 pounds of nitrogen and 200 pounds of phosphorus per acre increased yields about 30 percent under greenhouse conditions. Moravian barley produced maximum number of tillers (an indication of rate of plant enlargement) when 200 pounds per acre of potassium was added to the above combination. Results should be tested under field conditions.

On Black Mesa there are obvious differences in kind and amount of plant cover on what appear to be different, but yet related, sites. One site is on an old burn that occurred about 1880 in a spruce-fir forest. Here spruce reproduction is negligible and the herbaceous vegetation is still sparse. On other sites, generally with shallow and rocky soils, hairy goldaster (Chrysopsis villosa (Pursh) Nutt.) is prominent and there are very few plants of other species. In contrast, the majority of the area supports a lush growth of herbaceous vegetation with Idaho fescue (Festuca idahoensis Elmer) predominating.

It was suspected that fertility levels of the soils on the three sites might be partly responsible for the differences in herbaceous cover. For this reason, a study was designed to determine the effect of nitrogen (N), phosphorus (P), potassium (K), and micronutrients (M) on the productivity of the soils. Surface soils from the three sites described were used in pot tests under greenhouse conditions.

Methods

Approximately 100 pounds of the surface 6 inches of soil were collected from two randomly located areas within each of the three sites. The soil materials from each area within a site were composited in the field to form one sample per site. The soils were screened through 1/4-inch mesh to remove rocks and other extraneous material. The fertilizer treatments were as follows:

1. Ammonium nitrate equivalent to 100 pounds per acre elemental N.
2. Mono-basic calcium phosphate equivalent to 200 pounds per acre P_2O_5.
3. Potassium sulfate equivalent to 200 pounds per acre K_2O.

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[1] *Principal Plant Ecologist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

4. Micronutrients in a form approximating the stock solution described by Bonner and Galston[2] were added as follows:

	Pounds per acre
Boron (H_3BO_3)	11.2
Manganese ($MnCl_2$-$4H_2O$)	24.7
Zinc ($ZnSO_4$-$7H_2O$)	2.5
Copper ($CuSO_4$-$5H_2O$)	2.8
Molybdenum (H_2MoO_4-$4H_2O$)	1.8
Magnesium ($MgSO_4$)	2.2
Iron ($FeSO_4$-$7H_2O$)	0.4
Calcium ($CaSO_4$-$2H_2O$)	5.0
Sulfur (From above)	11.4

Greenhouse Procedures

The soils were evaluated in 6-inch plastic pots lined with plastic bags to prevent contamination. Each pot contained 1,600 grams of the screened and thoroughly mixed soil.

The required amount of each fertilizer for each treatment was dissolved in distilled water and added to each pot. Sufficient distilled water was applied at the beginning to assure adequate wetting of all soil in the pots. The soil was subsequently kept moist, but not wet. Photoperiod was 14 hours of combined artificial and natural daylight. Greenhouse temperature was about 70° F. during the daytime and 40° F. at night; humidity was not controlled.

Moravian barley (Hordeum vulgare L.) was used as a tester species; 10 seeds were planted in each pot. When germination was complete, each pot was thinned to the five most vigorous seedlings. These were allowed to grow until they reached the seed-in-boot stage on the control treatment. At that time the number of tillers was counted and herbage from all pots was harvested.

Results

Treatments were evaluated on the basis of germ nation, number of tillers, and herbage weight (tabl 1). Data were analyzed by methods of varianc and a probability level of 0.05 was accepted fc determining the significance of difference betwee treatments. Calculation of main effects and inte actions (shown in lower case, table 2) followed th procedure outlined by Cochran and Cox.[3]

Germination

Almost all seeds germinated in all pots, whic indicates fertilizers had no effect on germination For this reason these data were not analyzed statistically. Such high rates of germination (over 9 percent) probably could not be expected under fiel conditions, and certainly not with most native species In only one treatment was there any indication o possible effect. When the combination of NP was applied, there appeared to be a consisten depression of germination down to 93 percent or soils from all sites.

Herbage Yield

As suspected, the productivity of the three soils in this study was different (table 1). Average yields, without and with fertilizer, in grams per pot, green weight, were:

Soil type:	Without	With
Burn	27.7	32.2
Goldaster	30.1	33.9
Fescue	41.4	44.3

Maximum yields were obtained from the NPK treatment. Potassium, however, did not contribute significantly to the increase. Therefore, the NP combination could be expected to produce as much herbage as the NPK combination.

Although the NPK fertilizer (or the NP) did increase the production from all soils, it did not greatly change the relationship between them. This

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[2] *Bonner, J., and Galston, A. W. Principles of plant physiology. 499 pp. San Francisco: W. H. Freeman and Co. 1952.*

[3] *Cochran, W. G., and Cox, G. M. Experimental designs. Ed. 2, 611 pp. New York: John Wiley and Sons, Inc. 1957.*

Table 1.--Effect of fertilizers on herbage yield of Moravian barley (grams per pot, green weight) and number of tillers on soils from burn, hairy goldaster, and fescue sites

Treatment	Herbage yield				Tillers			
	Burn	Aster	Fescue	Average	Burn	Aster	Fescue	Average
	- - - Grams per pot - - -				- - - - Number - - - -			
Control	27.7	30.1	41.4	33.1	0	0	5.0	1.7
N (100 lb/acre)	34.1	34.9	45.3	38.1	1.7	0	7.7	3.1
P (200 lb/acre)	28.3	30.2	43.1	33.9	.7	.3	6.3	2.4
NP	35.2	39.1	46.2	40.2	1.0	3.0	9.0	4.3
K (200 lb/acre)	28.2	30.2	41.0	33.1	0	0	5.7	1.9
NK	36.4	36.1	43.9	38.8	4.0	.7	6.0	3.6
PK	28.3	31.1	44.1	34.5	1.0	1.3	9.0	3.8
NPK	37.1	38.3	50.0	41.8	5.7	4.0	10.0	6.6
Micronutrients (M)	27.8	29.8	41.4	33.0	0	0	3.7	1.2
NM	35.7	35.7	45.1	38.8	2.3	1.3	6.3	3.3
PM	28.5	31.8	43.0	34.4	.3	0	10.0	3.4
NPM	36.5	37.6	48.1	40.7	3.3	5.0	7.3	5.2
KM	28.0	29.5	39.9	32.5	0	0	6.3	2.1
NKM	35.2	36.0	43.1	38.1	2.3	1.0	8.0	3.8
PKM	28.1	30.9	44.0	34.3	0	1.7	6.3	2.7
NPKM	35.4	37.3	47.3	40.0	4.7	3.7	9.3	5.9

Table 2.--Analyses for single degree of freedom, main effect and interaction comparisons[1] of herbage yield and number of tillers on Moravian barley

Source	Herbage yield			Number of tillers		
	Degrees of freedom	Mean square	Main and interaction means	Degrees of freedom	Mean square	Main and interaction means
Total	143			143		
A (soils)	2	2120.03**		2	524.44**	
B (fertilizers)	15	95.21**		15	20.32**	
n	1		2.98**			1.03**
p	1		.89**			.85**
np	1		.20*			.17
k	1		.07			.34**
nk	1		.06			.13
pk	1		.13			.09
npk	1		0			.16
m	1		-.10			.02
nm	1		-.05			.06
pm	1		0			-.01
npm	1		-.15			-.02
km	1		-.33**			-.19
nkm	1		-.16			-.01
pkm	1		-.07			-.27**
npkm	1		-.05			.07
A x B (soils x fertilizers)	30	5.62**		30	4.28**	
Error	96	1.02		96	1.39	

[1] Calculations of main effects and interactions, shown in lower case, follow procedure outlined by Cochran and Cox (see text, footnote 3).

* Indicates significance at the 5 percent level.

**Indicates significance at the 1 percent level.

might indicate that higher rates of application, especially on the burn and goldaster soil, would be more productive, or it might indicate that some other factor in the soil is also deficient. It was observed during the course of the study that both the burn and goldaster soils dried more quickly than the fescue soil. This could have been related to soil texture or organic matter, but these factors were not measured.

The effect of fertilizers and the interaction of soils and fertilizers were both highly significant. In spite of this interaction, there were some consistencies in the results. On all soils, production was higher with amendments containing N. On two soils (burn and fescue) the amendment NPK produced maximum yields, and on the goldaster soils NPK was slightly below NP, but not different from it. The amendment NPM followed the same trend as NPK, but as with potassium, the micronutrients did not contribute significantly to the increased production.

Some of the main effects of fertilizers were important (table 2). Nitrogen (n) strongly increased production on all soils. Phosphorus (p) had an important main effect. Nitrogen and phosphorus (np) interaction was positive and significant at + 0.20 gram/pot. Neither potassium (k) nor the micronutrient (m) solution affected yields. The interaction (km) was significant ($P<.01$) due to the depressing effect of m. It is of interest that the signs of all treatment interactions involving the micronutrients were negative, indicating a depressing effect on yield. Micronutrients also depressed yields in a similar study on alpine soils from Wyoming.[4]

Number of Tillers

Without fertilizers, only soils from the fescue site produced tillers—an average of five per pot (table 1).

Nitrogen (N) and phosphorus (P) as separate applications increased the number of tillers, and in combination were superior to either amendment alone. Potassium (K) alone was not effective. Nitrogen (N) alone had no effect on the goldaster soils. Phosphorus (P) had some effect on all soils, and potassium (K) had only a slight effect on the fescue soils.

Combinations of NP, NK, and PK were more effective than the indivdual amendments alone, and tillering was maximum when all three elements were combined. Some other combinations, NPM and NPKM, were almost as good as the NPK, but a depressing effect (not significant, however) was indicated, probably due to the micronutrients.

The analysis of the number of tillers produced showed significant differences between soils, significant effects of fertilizers, and a strong interaction between soils and fertilizers ($p<.01$, table 2). The main effects of n, p, and k were all significant ($p<.01$). However, none of the interactions involving these three amendments was significant, which indicates that the effects were independent of each other. The pkm combination was significant ($p<.01$), but the sign was negative, again indicating a depressing effect. In this case some interaction between k and m and between p and m appears to be responsible.

Summary

Results from greenhouse studies on the effect of fertilizers cannot be expected to apply directly to field trials. They do, however, direct attention to those fertilizers which appear to be most promising for further tests under actual field conditions. In this case, the results indicate that substantial increases in herbage yields might be expected when nitrogen and phosphorus are applied in combination. The addition of potassium might have a tendency to increase the rate of enlargement of individual plants, thus increasing the amount of ground cover. Its addition to a combination of nitrogen and phosphorus might increase costs somewhat, but certainly should not decrease herbage yields.

The failure of the soils from the three sites to reach the same level of productivity might mean that tests of different rates of application would be in order. It is entirely possible, however, that other inherent soil factors, such as those connected with the moisture regime, may be involved. Hints of this effect were observed in the greenhouse in the differential rates of drying among the three soils.

Nevertheless, it appears that fertilization of soils on Black Mesa will be effective in increasing herbage yields. Field testing and cost-benefit studies are needed, however, as the first step toward a management program in this field.

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[4] *Johnson, W. M., and Smith, Dixie R. Pot tests of productivity and nutritive status of three alpine soils in Wyoming. U. S. Forest Serv. Res. Note RM-75, 7 pp., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

Agriculture --- CSU, Ft. Collins

U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM-154

REST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Chemical Control of the Arizona Five-Spined Ips

Ips lecontei Sw. (Coleoptera: Scolytidae)

H. Eugene Ostmark[1]

The major purpose of this research was to find an insecticide that could be applied to high-value ponderosa pines in southwestern home and campsites to prevent attacks by the Arizona five-spined Ips. In addition, a bark-penetrating fumigant was sought to treat Ips-infested pines during dry months when cutting and burning was ruled out as a control method because of forest fire danger. Allowable uses of some pesticides studied may have been restricted since this research was completed.

Much research has been done with insecticides to determine their effectiveness on various bark beetle species belonging to the genera *Ips* and *Dendroctonus*. Hetrick and Moses (1953) found benzene hexachloride to be the most effective out of nine insecticides tested to prevent *Ips* and cerambycid injury to stacked pine pulpwood. Moore (1957) tested four chemicals against *Dendroctonus brevicomis* and *Ips confusus*; lindane proved most toxic to *I. confusus* followed by isodrin, DDT, and toxaphene. Lyon (1959) also found lindane to be toxic to *I. confusus*, and he prepared directions for its use (Lyon 1960.)

Hetrick (1957) treated slash pine logs with carbaryl 50wp (wettable powder) and Delnav 25 wp. Carbaryl wp applied at concentrations of 0.1, 0.2, 0.4, and 0.8 percent protected the logs from scolytid and cerambycid injury for approximately 6 weeks; Delnav, at the same concentrations, protected for 3 weeks.

Massey (1960) treated 745 green ponderosa pines (*Pinus ponderosa* Laws.) in New Mexico with 2 percent DDT ec (emulsifiable concentrate) at the end of May and the middle of July; 286 trees were left untreated. In September, *D. brevicomis* (= *barberi*) killed 103 untreated and 3 treated trees.

Smith (1967) protected ponderosa pines for 1 year against *D. brevicomis* with a 2.5 percent diesel oil solution of lindane, and for over 2 months with a 2.5 percent water emulsion of lindane.

Bark-penetrating fumigant sprays have effectively killed bark beetles and their broods beneath the bark of infested trees. Massey et al. (1953) killed *Dendroctonus ponderosae* (= *monticolae*) in standing trees with water emulsion of ethylene dibromide (EDB).

Kinghorn (1955) tested emulsions of orthodichlorobenzene, EDB, DDT, and chlordane at the rate of 0.8 pound of active ingredient per 5 U. S. gallons of emulsion containing 20 percent fuel oil against adults and young larvae of *I. interpunctus*. DDT and chlordane killed parent adults, but mortality of the progeny under the bark was negligible for all treatments. However, he found emulsions of EDB, aldrin, heptachor, lindane, and dieldrin at 3.2 pounds active ingredient per 5 U. S. gallons of emulsion effective against *D. ponderosae*. Struble

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and Hall (1955) recommended toxic penetrating oil applications consisting of 1 part orthodichlorobenzene to 6 parts "stave oil" or diesel fuel, or 1.5 pounds EDB to 5 gallons of oil, for killing I. confusus.

Materials and Methods

On the basis of past results, DDT, lindane, and carbaryl were selected to test as residual sprays. EDB, Nemagon,[2] and Fumazone were the bark-penetrating fumigants tested; Nemagon and Fumazone were different formulations of the same nematicide (1,2-dibromo-3-chloropropane), which had never been tested against Ips beetles.

Residual Sprays

In the residual spray trials, the insecticides tested were DDT ec at 0.5, 1.0, and 2.0 percent; and lindane ec and carbaryl ec at 0.25, 0.5, and 1.0 percent. Carbaryl wp was tested at 1.0 percent. All treatments were replicated five times in each of two experiments. The first was conducted during 1960, a year of high Ips population; the second during 1961, a year of low Ips activity. In the second test, 1.0 percent DDT wp was added.

Fifty-five 6-foot logs, 4 to 6 inches in diameter, were cut and strewn around the shady forest floor in the first test. For the second test, 65 logs were cut, including 10 left as checks.

The insecticides were sprayed to the point of runoff on randomly selected logs with compressed-air garden sprayers. The logs were examined daily for the first 35 days, then weekly. A log was considered attacked at the first sign of Ips boring dust.

To determine if the attacking beetles had survived to construct mating chambers and egg galleries under the bark, four 6-inch-square bark samples (1 square foot total) were cut from the top, each side, and the bottom surface of each log 14 days after the first boring dust was noted (fig. 1). A special tool was constructed for cutting the squares. The presence of a mating chamber constituted a successful attack, and the length of egg galleries constructed indicated the survival of attacking Ips.

The infested trees were all relatively thin barked; the maximum bark thickness in the samples never exceeded 20 mm.

Bark-Penetrating Fumigants

In the test of the three bark-penetrating fumigants, EDB was chosen because of its proven effectiveness against other bark beetles; Fumazone and Nemagon because their boiling point is 196° C. as compared with 131° C. for EDB, and their solidifying point is -1.0° C. as compared with +9.0°C. for EDB. All were mixed at the rate of 2 pounds active ingredient plus 8 ounces of the emulsifiers Triton X-151 and Triton-171 and fuel oil to make 1 gallon. This mixture was added to 4 gallons of water to make 5 gallons total mix.

Standing trees infested with I. lecontei were felled and bucked into 6-foot logs. Each fumigant was sprayed to runoff on eight logs with a compressed-air garden sprayer; eight were left untreated as checks. Twenty days later, four 6-inch squares of bark were cut from each log, and living and dead Ips, predatory larvae, and wood borer larvae were counted. In addition, the bark thickness of each sample was measured.

Figure 1.--Bark samples cut 14 days after first Ips attacks from logs sprayed with residual insecticides. Note sampling tool.

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[2] Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.

Results

Residual Sprays

No *Ips* attacks were found later than 29 days after the logs were cut in the year of high *Ips* populations, although the logs remained on the ground for 92 days. In the second year's test, two logs were attacked 58 days after cutting; all logs were left on the ground for 72 days.

The first year the residual sprays were tested was one of heavy *Ips* infestation and high pine mortality. The first treatments were made on May 26. Table 1 shows the length of time the various chemical treatments kept the freshly cut logs free of *Ips* attacks. The 1.0 percent carbaryl wp was obviously superior to all other treatments since none of the five treated logs became infested.

Of the five logs treated with 1.0 percent lindane ec, three became infested at an intensity of two attacks per square foot, but none of the attacking beetles survived to make egg galleries (table 2).

The next year *I. lecontei* populations were low. The experiment was repeated, and a 1.0 percent DDT wp was added since the carbaryl wp proved more effective than the carbaryl ec. The logs were sprayed on June 3.

Table 1 shows that three of five logs treated with 1.0 percent carbaryl wp and four of five treated with 0.5 percent lindane never became infested by *Ips* spp. However, all lindane treatments and the 1.0 percent DDT wp had the fewest *Ips* surviving to make galleries under the bark (table 2).

Bark-Penetrating Fumigants

All bark-penetrating fumigants killed 92 percent or more of *I. lecontei* under the bark (table 3). Ethylene dibromide also killed 22 predatory larvae of *Enoclerus* spp. and *Temnochila* sp., but Nemagon did not kill any of eight predators encountered.

A chi-square test showed that the 100 percent mortality caused by EDB was superior to that caused by either Nemagon (95.7 percent) or Fumazone (92.1 percent), but all three fumigants caused satisfactory *Ips* mortality compared to controls (7.1 percent).

Table 1.--Number of days freshly cut logs remained free of *Ips* attack following treatment with residual sprays in 1960 under high (H) and in 1961 under low (L) intensities of *Ips* infestation. Unless otherwise noted, all insecticide formulations were water emulsions (ec)

Treatment	Log 1		Log 2		Log 3		Log 4		Log 5	
	H	L	H	L	H	L	H	L	H	L
	- - - - Number of days - - - -									
Carbaryl:										
0.25 percent	12	17	18	19	18	22	21	22	25	26
0.50 percent	8	10	9	25	11	25	12	25	13	28
1.00 percent	7	17	7	22	9	26	20	26	(1)	26
1.00 percent wp	(1)	25	(1)	25	(1)	(2)	(1)	(2)	(1)	(2)
Lindane:										
0.25 percent	20	22	21	28	24	31	(1)	58	(1)	58
0.50 percent	9	25	20	(2)	25	(2)	(1)	(2)	(1)	(2)
1.00 percent	11	10	29	26	(1)	33	(1)	(2)	(1)	(2)
DDT:										
0.50 percent	11	7	13	25	21	26	(1)	31	(1)	(2)
1.00 percent	8	7	20	10	20	22	(1)	26	(1)	28
2.00 percent	9	7	23	33	29	57	(1)	(2)	(1)	(2)
1.00 percent wp	(3)	22	(3)	26	(3)	31	(3)	(2)	(3)	(2)
Control (untreated)	4	25 31	11	26 31	11	28 31	13	28 (2)	(1)	28 (2)

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[1] Not attacked at the end of 92 days.
[2] Not attacked at the end of 72 days.
[3] Not tested in 1960 (H).

Table 2.--Inches of *Ips* galleries and numbers of mating chambers in logs treated with residual sprays while still green, in 1960, under high (H) and in 1961, under low (L) intensities of *Ips* infestations. Unless otherwise noted, all insecticide formulations were water emulsions (ec)

Treatment	Logs infested		Mating chambers		Gallery	
	H	L	H	L	H	L
	Number		Attacks per square foot		Inches per square foot	
Carbaryl:						
0.25 percent	5	5	3.8	3.2	50.2	31.0
0.50 percent	5	5	4.6	4.2	54.2	48.0
1.00 percent	4	5	2.0	8.8	23.7	46.0
1.00 percent wp	0	2	0	1.5	0	15.5
Lindane:						
0.25 percent	3	5	6.0	1.3	79.7	6.3
0.50 percent	3	1	2.0	0	11.7	4.0
1.00 percent	3	3	2.0	1.0	0	2.3
DDT:						
0.50 percent	3	4	3.0	2.0	51.2	26.2
1.00 percent	3	5	4.0	3.2	58.3	22.6
2.00 percent	3	3	2.3	2.5	25.0	35.0
1.00 percent wp	(1)	3	(1)	.5	(1)	4.5
Control (untreated)	4	8	6.2	8.0	77.3	64.0

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[1] Not tested in 1960 (H).

Discussion and Conclusions

The maximum length of time the three residual insecticides gave protection was difficult to assess because 3 out of 15 check logs never became in-

Table 3.--Effects of bark-penetrating fumigants on number of *Ips lecontei* in infested trees

Fumigant	Larvae		Pupae		Adults		Mortality
	Live	Dead	Live	Dead	Live	Dead	
	- - - - - - Number - - - - -						Percent
EDB	0	256	0	96	0	256	100.0
Nemagon	11	171	1	29	6	209	95.7
Fumazone	49	291	0	73	6	279	92.1
Control (untreated)	100	6	22	17	269	7	7.1

fested. However, 2 months' protection would be a reasonable estimate for carbaryl wp. DDT wp, and the lindane sprays based on the low number of successful attacks and egg galleries per square foot in treated logs that lay on the ground for over 2.5 months. Also, living trees are normally more difficult for beetles to infest than are logs, since the living trees exude resin that frequently completely engulfs attacking beetles. Therefore, the addition of a residual insecticide would make successful bark beetle attacks more unlikely on living trees than on logs.

The bark-penetrating fumigants were all effective. The lower Ips mortality rate in the Fumazone-treated logs was due mainly to 41 live larvae found in 2 of the 32 bark samples taken. This suggests that a section of bark was not covered properly with the Fumazone emulsion.

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*Address requests for copies to the originating office.

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U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM-155

REST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Nocturnal Radiation Loss Estimates for a Forest Canopy

James D. Bergen[1]

Average nocturnal net radiation over a conifer canopy measured with a suspended radiometer was compared with that estimated from the black body emission at the average air temperature below the radiometer, and the sky radiation measured at some distance away. Values agreed within 20 percent for 5 nights; measured radiation averaged 9 percent higher than the estimate. No systematic variation was found with windspeed or humidity.

Most radiometers are expensive and relatively fragile instruments. Their performance may be critically affected by such common hazards as precipitation and dust. These hazards are particularly severe for the unventilated instruments which, for lack of convenient power sources, must of necessity be used in most field studies. Maintenance difficulties are compounded when the instruments must be installed in a relatively inaccessible position such as above a forest canopy. A reasonable method of approximating the net radiation balance without installing and maintaining such an instrument would be preferable for most purposes.

The most convenient parameters on which to base such an estimate are the local air temperature, and the sky radiation measured nearby with more easily maintained equipment. The latter measurements can be routinely made with little difficulty. Average downward radiation from the night sky for intervals greater than half an hour should vary little between stations at the same elevation over areas of the order of 10 km^2 under most conditions of cloud cover and atmospheric moisture.

This Note briefly describes the problems encountered in such an approximation and compares resulting estimates of net radiation with measured values for data taken on 5 autumn nights in the Colorado Rockies.

The Approximation

The nocturnal radiation balance at the top of a forest stand may be expressed as

$$R_N = R_B - R_{sk} \qquad [1]$$

where R_N is the net radiation loss, R_{sk} is the downward flux of radiation from the sky, and R_B is the total thermal emission from the canopy and the soil surface. There may be appreciable temperature differences between various levels in the forest canopy and between the soil surface and the canopy, but in the absence of information on the distribution of radiating surface with height, a practical approach is to regard the canopy and soil surface as equivalent to an isothermal layer radiating at the average temperature of the actual canopy; that is, $\bar{T}$ so that

$$R_B = \sigma \bar{T}^4 \qquad [2]$$

where σ is the Stephan-Boltzman constant, and where the emissivity of the canopy elements and soil surface is assumed to be unity. In most situ-

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ations, however, foliage surface temperatures are not measured. Such temperatures for a particular foliage element could be measured with little difficulty, but the sampling problems to obtain an average temperature are formidable. In this approximation, it will be assumed that $\overline{T}$ is equal to the average air temperature in the canopy layer measured at some point between the trees. Because the actual foliage temperatures must be less than the air temperatures at any particular level in the canopy, this assumption should lead to an overestimate of R_B and thus of R_N. The differences would amount to about 7×10^{-3} ly min^{-1} for each degree of the difference between average foliage and air temperature at temperatures near 5° C. A wide range of foliage-air temperature differences are reported in the literature for leaves of various species and with differing radiation conditions and ventilation. For conifer needles, the temperature drop needed to sustain a high radiation load is of the order of one or two degrees,[2] and observed nighttime differences as measured by Wellington[3] are less than a degree. Since the needles supply the bulk of the radiating surface in a conifer canopy, the error in R_B due to foliage-air temperature differences should not exceed about 14×10^{-3} ly min^{-1}, and errors of this magnitude could be expected only with high net radiation losses.

Errors due to the temperature drop from the soil surface to the air at the lowest level of measurement are not as readily estimated. They will depend on the local windspeed, roughness, and the thermal properties of the surface as well as the total canopy cover viewed from the stand floor. Because temperature gradients of as much as 4° C. over a meter are not implausible, judging from the literature, this effect would seem to be a potential source of major error. The error in the calculated emitted radiation due to differences between the air temperature and that of the soil surface or foliage surfaces would decrease with increasing windspeed.

In general, the radiometer used to measure R_{sk} and the point at which R_N is to be estimated will not be at the same level. In most cases, the radiometer will be at a lower level, while the estimate will be for a point on some nearby slope. If these two levels are written as Z_1 and Z_2, respectively, the measured value of R_{sk} will exceed that applicable to the level Z_2 by the downward flux of radiation emitted by the air and water vapor between the levels Z_1 and Z_2. Since this emission is a function of the temperature and specific humidity of this layer, it could be computed in a routine manner—given a profile of these quantities with height—from a number of published tables or from nomograms such as the Elsasser diagram.[4] Such profiles are not generally available in most field studies, but upper bounds for such emission can be estimated from surface observations, such as a hygrothermograph recording, by assuming that neither temperature nor humidity changes through the layer. Emissions computed in this manner from temperatures and relative humidities in climatological tables vary from 10^{-3} to 10^{-1} ly min^{-1} for a layer of air 50 meters thick. It is apparent from such calculations that serious error will result in Z_1 and Z_2 differ by more than a few meters in the coastal regions of the United States, but that Z_2 may exceed Z_1 by many tens of meters in the Rocky Mountain region without appreciable error. This will be shown to be the case for the following observations.

Observations

Net nocturnal radiation loss was measured at a point in the upper reaches of a conifer canopy on a slope in the fall of 1964 at Fraser Experimental Forest. The experimental layout is shown in figure 1. These measurements were made with an unventilated Soumi-type radiometer equipped with the remote-reading and integrating thermistor circuit developed by Goodell.[5] This instrument was suspended at point A (fig. 1) by cable at a height of about 10 meters above the floor of the stand. The maximum tree height on the slope was about 20 meters, and the average height was 5 meters. All the vegetation within a radius of about 10 meters was below the instrument. Vegetation con-

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[2] *Gates, D. M. Leaf temperature and energy exchange. Arch. Met. Geophys. u. Biokl. B. 12: 321-336. 1963.*

[3] *Wellington, W. G. Effects of radiation on the temperature of insect habitats. Sci. Agr. 30: 209-234. 1950.*

[4] *Johnson, J. S. Physical meteorology. 393 pp. New York: John Wiley & Sons. 1954.*

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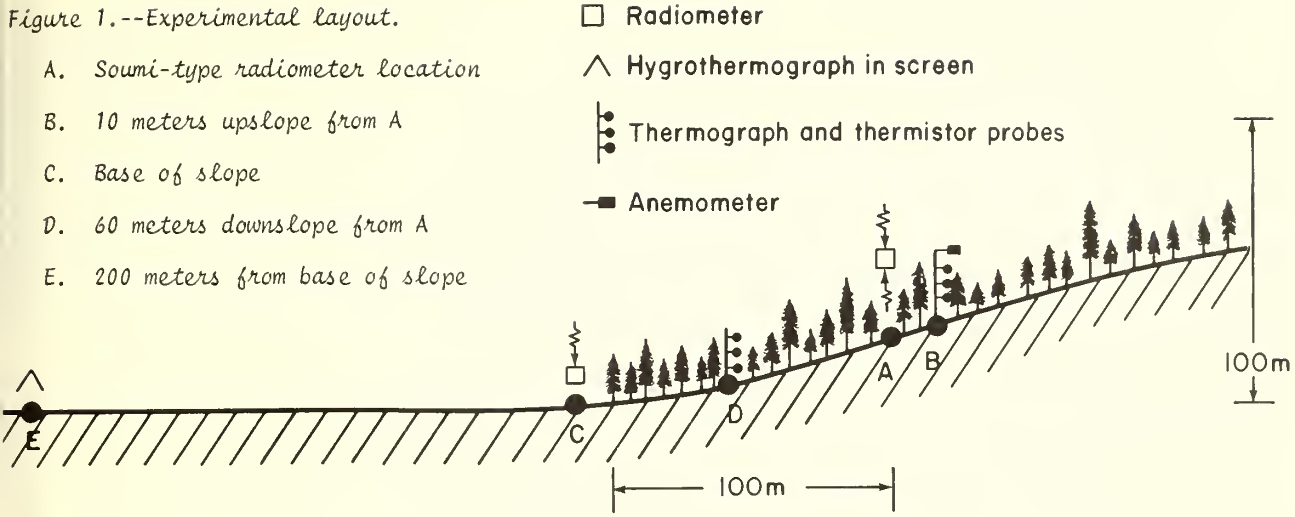
Figure 1.--Experimental layout.

A. Soumi-type radiometer location
B. 10 meters upslope from A
C. Base of slope
D. 60 meters downslope from A
E. 200 meters from base of slope



sisted of lodgepole pine, spruce, and some aspen trees.

Air temperature was measured at various levels 10 meters upslope (point B) from the instrument position and at a point (D) about 60 meters downslope. These measurements were made with remote-reading thermistors and bimetal thermographs. Windspeeds at point (B) were measured with a recording heated thermopile anemometer on a 1-meter-long cross arm attached to a tree at a level 16 meters above the slope surface.

Sky radiation was measured at (C) near the margin of the stand at the base of the slope, with a ventilated radiometer, mounted at 1-meter height, and shielded to respond to hemispherical radiation. Relative humidity and temperature data were available from a hygrothermograph maintained in a standard instrument shelter about 200 meters from the base of the slope (E).

The ventilated radiometer was at a level approximately 20 meters below the position of the radiometer on the hillside. The period of measurement was from 1800 LST, at which time the radiometer sites were in shadow, to 0500 LST the following morning, corresponding approximately to local sunrise.

Errors Due to Exposure

The use of measurements at (C) to compute the net radiation balance at the hillside radiometer station presumes either that the trees extending above the level of the slope radiometer and in the field of view of the radiometer at the base of the slope did not provide an appreciable contribution to the back radiation balance in a similar manner at the two sites. Since no measurement of canopy cover was made at the position and level of the slope radiometer, only an order of magnitude estimate may be made for this error.

Measurements with a chain and hypsometer showed that the average height of those trees within a 20-meter radius of a point directly below the suspended radiometer which rose above the level of the radiometer was about 20 meters. These trees were spaced on the average more than 5 meters apart. If we regard the screening effect of these trees on the view factor between the radiometer and the night sky as being analogous to that which would occur for a radiometer at the surface of the slope and surrounded by a dense stand 10 meters high, then by the calculations presented in Geiger's work,[6] about 50 percent of the instrument's field of view for the night sky would be obscured. However, these calculations are for a stand so dense that it may be considered opaque; that is, a solid wall. The average crown diameter of the trees above the radiometer level was only about a meter, as estimated from the ground. Such a tree at a distance of 10 meters from the radiometer would only subtend about 0.1 radians of arc.

If we approximate the radiometer position as the center of concentric polygons formed by trees 10 meters in height, spaced 5 meters apart, with an

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[6] Geiger, R. *The climate near the ground.* 494 pp. Cambridge, Mass.: Harvard University Press. 1957.

effective crown diameter of 1 meter, the 12 trees of the innermost polygon subtend a total of only 1.14 radians of arc from the radiometer. The reduction in the view factor between radiometer and sky would be only 0.18 of that caused by a solid wall of the same height, and would be 0.10. The corresponding contribution for the second polygon, computed in the same way, is less than 0.02. On the basis of this very approximate model, and neglecting the variation of temperature with height in the canopy, it would appear that the radiation loss measured by the suspended radiometer could be less than that which would be measured above all the trees on the slope by about 15 percent.

The view of the radiometer at the base of the slope is also obstructed by the margin of the stand. If we consider this margin as one boundary of a clearing, Geiger's calculations imply that sky radiation measured by the radiometer may be as much as 15 percent less than would be the case if no vegetation impeded the field of view.

It should be noted that the two errors mentioned will operate in the opposite sense in respect to the comparisons made in this paper. Thus, the suspended radiometer may indicate net radiation values low by 12 percent, and the analogous error in the measured sky radiation could cause an overestimate of the net radiation computed as the difference between the sky radiation (R_{sk}) and the black body emission (R_B).

Results

The average net radiation measured at (A) is shown in table 1 as R_o for each of the 5 nights. The average air temperature ($\bar{T}$) was estimated by interpolation between points (C) and (D) and the associated thermal emission (R_B) calculated from relation [2]. The average sky radiation R_{sk} computed from the radiometer readings, and R_N computed by relation [1] is also listed for each night. The R_N and R_o sequences are remarkably close, considering the simple model on which the approximation is based: The maximum relative error is 25 percent and average relative error is 9 percent, with R_o exceeding R_N both in the average and on each night except on September 16. The sign of the divergence is surprising, since most of the error factors would cause R_N to exceed R_o.

The average windspeeds measured at (C) are low for all the nights, ranging from 30 to 52 cm sec^{-1} (table 1). The relative error in R_N does no show the expected tendency to become more negative with increasing windspeed (in fact, the maximum positive error appears at the lowest speed on the night of September 10), nor does the relative error appear to vary consistently with the specific humidity computed from measurements at poin (E).

The sign of the divergence suggests that the upper canopy is dense enough below the radiometer position at (A) to allow the foliage in the region about 3 or 4 meters below the radiometer to dominate the radiation exchange with the nigh sky. Thus, the temperature ($\bar{T}$) was too low by a degree or so to be representative of the radiation exchange above the canopy at (C) noted above. a correction for this effect would require information about the distribution of radiating surface within a canopy, which is not easily obtained in situations where this method would be used. On the whole, however, the estimate agrees well with the measured values, and the method can be recommended for practical problems in environments similar to the experimental site as long as limits on elevation differences are imposed by the prevailing air temperature and relative humidity are considered.

Table 1.--Estimated and measured radiation losses, 1800-0500 LST, September 1964

Date measured	Average air temperature ($\bar{T}$)	Midslope black body (R_B)	Sky (R_{sk})	Estimated (R_N)	Measured (R_o)	$\frac{R_o-R_N}{R_o}$	Windspeed	Specific humidity
	°C.	- - - - -	- Langleys min^{-1} -	- - - -		Percent	Cm sec^{-1}	Gm. cm^{-3} x 10^6
September 10	2.9	0.473	0.453	0.020	0.025	20	30	1.8
14	1.9	.477	.460	.017	.018	5	40	2.0
16	.3	.458	.431	.027	.025	-8	46	1.7
17	.6	.457	.430	.027	.030	10	44	1.7
25	6.8	.501	.470	.031	.035	11	52	3.2

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U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM- 156

REST SERVICE
. DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Alkali Sacaton Seedlings: Germination and Survival in an Agar and Soil Medium[1]

Earl F. Aldon[2]

Laboratory experiments indicate that germination and survival of alkali sacaton seedlings are improved by: (1) An agar medium to provide moisture for germination, (2) mulch, (3) planting in soils containing 7 percent moisture by weight, and (4) watering on the fifth day after planting.

Alkali sacaton (*Sporobolus airoides* Torr.) seeds germinate best under moisture tensions of 0 atm.,[3] which helps to explain why these plants are confined mainly to areas that are frequently flooded. Also, unless new seedlings receive additional moisture between the fifth and tenth day following germination, survival is reduced from above 90 to below 76 percent.[4]

Established, well-managed alkali sacaton stands are able to withstand drought and excessive grazing, and help to stabilize soils.[5] If a method were known that would increase germination and survival of alkali sacaton on arid soils, stands of this species could be established; those arid soils could be stabilized, and their productivity increased.

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[1] *Research reported here was conducted in cooperation with the Bureau of Land Management, U. S. Department of the Interior, Albuquerque, New Mexico.*

[2] *Principal Hydrologist, located at Albuquerque, in cooperation with the University of New Mexico; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[3] *Knipe, O. D. Effects of moisture stress on germination of alkali sacaton, galleta, and blue grama. J. Range Manage. 21: 3-4, illus. 1968.*

[4] *Aldon, Earl F. Alkali sacaton seedling survival and early growth under temperature and moisture stress. U.S.D.A. Forest Serv. Res. Note RM-136, 4 pp., illus. 1969. (Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.)*

[5] *Aldon, Earl F., and Garcia, George. Summer deferred grazing can improve deteriorated semidesert ranges. U.S. Forest Serv. Res. Note RM-95, 3 pp. 1967. (Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.)*

The laboratory experiments reported here were designed to test (1) whether an agar medium would provide zero or nearly zero moisture tension for 5 days for the germinating seeds; and (2) whether mulches and additional water were necessary to help the seedlings become established. Sandy alluvial soils from the Rio Puerco drainage in New Mexico were used for all experiments.

Exploring Possibilities

Agar solutions were used to prepare a medium on which moisture stress for germination would be minimal. Plates of 2.0 percent agar in water were prepared by autoclaving 500 ml. of distilled water with 10 g. of dried agar for 20 minutes at 121° C. and 15 p.s.i. This liquid was poured into sterile quartered petri dishes, 100 x 15 mm., and cooled overnight. The quartered sections of agar were used for all laboratory tests.

In the first test, germination on agar plates was compared with that on saturated blotters[6] Ten alkali sacaton seeds were placed in each of 12 petri dishes containing agar and 12 containing blotters. Germination at 85° F. (the optimum temperature for growing these seedlings)[4] compared after 15 days, showed no differences between blotters and the agar.

Then, 10 petri dishes of agar were streaked with soil from the field, covered, and left at room temperature (72° F.) for 10 days. Since the agar contains no nutrients, few bacteria and fungi that might be detrimental to young alkali sacaton seedlings developed.

Next, uncovered agar sections were exposed for 10 days to room temperature of 72° F. and growth chamber temperature of 85° F. In 3 days the sections had completely dried out. This test showed that mulching would be necessary to postpone rapid drying, since seedlings take 5 days to emerge from the soil. [4]

To test the effect of dry-soil mulch on germination and survival of seedlings, a randomized block experiment with three replications and three different concentrations of agar plates was set up on moist and on dry soils. Treatments consisted of plates of 1.5, 1.75, and 2.0 percent agar placed on both moist soil (7.0 percent moisture by weight) and on air-dry soil. For the moist-soil test, soil taken from the field was air dried, set in 1-quart milk cartons, saturated, and allowed to dry to 7.0 percent moisture by weight. Agar plates were placed on the surface of the soil, five seeds were placed on the agar, and the plates were covered with a 1/4-inch mulch of air-dry soil. For control pots, seeds were placed directly on the 7 percent moist soil and covered with a 1/4-inch mulch of air-dry soil. For comparison, air-dry soil was placed in a like number of milk cartons and similarly planted with alkali sacaton seeds on agar plates. All pots were placed in a greenhouse where temperatures were maintained at 85° F. Five days later, all pots were watered with 38 cc. (about 1/4-inch) of distilled water.

Ten days after planting, no seedlings had emerged in any of the pots. Excavation of all pots showed that no seeds germinated on the agar plates on dry soil. The dry soil above and below the agar plate caused it to dry rapidly before seeds could germinate.

In the moist-soil test (7 percent initial moisture), no seeds germinated in the control pots. But in the moist-soil pots with agar plates, germination was upward of 80 percent (several seeds were lost in excavating, so exact counts could not be made). No seedlings emerged, however; those that germinated were coiled beneath the hard soil surface. It was surmised that the agar stayed intact on the moist soil long enough for germination, but the dry-soil mulch absorbed moisture from the agar and formed a crust the seedlings could not penetrate.

To get alkali sacaton seedlings to emerge and survive for at least 10 days, it seemed necessary to provide: (1) an agar medium that supplied optimum moisture for germinating seed, (2) soil containing some moisture (at least 7 percent), (3) a mulch that would not interfere with the seedlings' emergence or dry out the agar excessively, and (4) water on the fifth day after planting.

Testing Hypotheses

To test seedling survival, a randomized block design was used with four replications in relatively

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[6] *Details of standard blotter procedures are described by Knipe (see footnote 3).*

able 1.--Average percent of soil moisture, by mulch type, at start and end of study

Mulch	Soil moisture		
	Start	End	Loss
	Percent by weight		
erlite	7.1a	5.6a	1.5
ry soil	6.7a	4.1b	2.6
ermiculite	6.8a	3.8c	3.0
et soil	6.8a	1.8d	5.0
Average	6.8	--	3.0

ny two means within columns not followed by he same letter are significantly different at .05 level according to Duncan's new multiple ange procedure. (See: Steel, R. G. D., and orrie, J. H. Principles and procedures of tatistics. pp. 107-109. New York: McGraw-ill Book Co., Inc. 1960.)

ry soil under four different mulches. Quart conainers were filled to known weights with dry soil, hen saturated with distilled water and allowed to ry in the greenhouse at 85° F. until the soil eached about 7 percent moisture content by weight. ach pot was then planted with five alkali sacaton eeds on a section of 2 percent agar. Seeds in our pots were covered with known weights of /4-inch dry soil (control), four with 1/4-inch saturted soil (mixed to a wet mud consistency), four vith 1/4-inch vermiculite, and four with 1/4-inch erlite. Five days after planting, all pots were vatered with 38 cc. of distilled water. Seedlings vere counted and soil moisture contents deternined on the 10th day after planting. Analysis of variance was run on seedling survival, and on soil moisture before and after the 10-day trial.

No seedlings survived under the wet- or dry-soil mulches. Again, the seedlings were unable to penetrate the crusted soil. Fifteen seedlings (75 percent) were alive after 10 days under vermiculite and 12 seedlings (60 percent) under the perlite mulch. Survival figures for vermiculite and perlite were not significantly different.

Before planting, soil moisture averaged 6.8 percent for all pots. At the end of the mulching experiment, soil moisture was significantly different for each treatment (table 1). Perlite proved best able to hold moisture. Soil moisture losses were greatest (5.0 percent) under wet soil.

The range of soil moisture tested was well below optimum for germinating alkali sacaton. The beginning moisture percentage of 6.8 represents about 0.33 atm. tension for these sandy alluvial soils; tensions at the end of the study were 0.6 atm. under perlite and 7.0 atm. under vermiculite.

Conclusions

1. Alkali sacaton can germinate and survive under common field soil moisture conditions that are much less than optimum.
2. Agar plates may be substituted for optimum soil moisture conditions to better enable alkali sacaton seeds to germinate.
3. Vermiculite and perlite mulches helped hold soil moisture; more seedlings survived than with either wet- or dry-soil mulches.
4. Laboratory results seem to justify field tests. Field trials will be conducted to test ways of using agar plates for germinating and establishing alkali sacaton on severely eroding flood plains.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-157

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Board-Foot Volumes to a 6-Inch Top for Lodgepole Pines in Colorado and Wyoming

Clifford A. Myers[1]

Presents tables and equations for volume in board-feet Scribner Rule and for corresponding point-sampling factors.

Recent changes in regional measurement standards for lodgepole pines (Pinus contorta Dougl.) include reduction of merchantable top diameter to 6 inches and stump height to 8 inches. The four tables presented here give tree volumes in board feet and corresponding point-sampling factors for these utilization limits. Tree heights may be in feet (tables 1 and 2) or in logs and half logs (tables 3 and 4). Equations for tree volume and for volume per square foot of basal area used to prepare the tables are given in table footnotes.

Standards for assembly and analysis of data were as reported previously,[2] except for the new utilization limits. Previous suggestions for use of volume tables and for cruising with point-sampling factors also apply to the tables presented here.

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[1] *Principal Mensurationist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[2] *Myers, Clifford A. Volume tables and point-sampling factors for lodgepole pine in Colorado and Wyoming. U. S. Forest Serv. Res. Pap. RM-6, 16 pp. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo. 1964.*

Table 1.--Volumes in board feet Scribner Rule,
lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 6 inches inside bark
Stump height 0.7 foot

Diameter breast height outside bark (inches)	Total height in feet									Basis: Trees
	30	40	50	60	70	80	90	100	110	
	Board feet									
6	9	14	19	24						20
7	14	21	28	35	41					34
8	20	29	37	46	55	63				45
9	27	37	48	59	70	81				59
10		47	60	74	87	100	113			101
11		58	73	89	105	121	137			92
12		69	88	107	125	144	163			70
13		82	104	125	147	169	191	213		32
14			120	146	171	196	221	247	272	20
15			138	167	196	225	254	284	314	9
16			158	190	223	256	290	324	358	20
17			178	215	252	290	328	367	406	11
18				241	283	326	369	412	456	12
19				268	316	364	412	460	509	2
20				299	352	405	458	511	564	1
21				331	389	447	506	564	622	2
22				364	428	492	556	620	684	3
23				399	468	538	608	678	747	2
24				435	511	587	663	738	814	1
Basis: No. trees	2	24	125	171	125	72	15	2	0	536

Block indicates extent of basic data.

Derived from $V = 0.01202\ D^2H - 6.00933$ for D^2H to 22,800.
$V = 0.01263\ D^2H - 19.76641$ for D^2H larger than 22,800.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 2.--Volumes in board feet Scribner Rule per square foot of basal area,
lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 6 inches inside bar
Stump height 0.7 foot

Diameter breast height outside bark (inches)	Total height in feet								
	30	40	50	60	70	80	90	100	110
	Board feet								
6	40	62	84	106					
7	47	69	91	113	135				
8	51	73	95	117	139	161			
9	54	76	98	120	142	164			
10		78	100	122	144	166	188		
11		80	102	124	146	168	190		
12		81	103	125	147	169	191		
13		82	104	126	148	170	192	214	
14			105	127	149	171	193	215	238
15			106	128	150	172	194	217	240
16			106	128	150	172	195	218	241
17			107	129	151	173	197	220	243
18				129	152	175	198	221	244
19				129	153	176	199	222	245
20				130	154	177	200	223	246
21				131	154	177	201	224	247
22				132	155	178	201	224	248
23				132	156	179	202	225	248
24				133	156	179	202	226	249

Derived from $V/B = 2.20432H - 1101.78114/D^2$ above dotted line.
$V/B = 2.31611H - 3624.07136/D^2$ below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 3.--Volumes in board feet Scribner Rule, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 6 inches inside bark
Stump height 0.7 foot

Diameter breast height outside bark (inches)	Number of 16.5-foot logs to 6-inch top										Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
	- - - - - - - - - - - - - - Board feet - - - - - - - - - - - - - - - -										
6	15	20									20
7	16	23	30	36	43						34
8	18	27	35	44	53	61					45
9		31	42	52	63	74	85	95			59
10		36	49	62	75	88	101	114	127		101
11		41	57	72	88	104	120	135	151		92
12		47	65	84	102	121	140	158	177	196	70
13			75	96	118	140	161	183	206	228	32
14			85	110	134	159	185	211	236	262	20
15			95	124	152	181	211	240	270	299	9
16				139	171	205	238	271	305	338	20
17					192	230	267	305	342	380	11
18					214	256	298	340	382	424	12
19					238	284	331	377	424	471	2
20						314	365	417	468	520	1
21						344	401	458	514	571	2
22						377	439	501	563	625	3
23						411	478	546	614	682	2
24						446	520	593	667	740	1
Basis: No. Trees	19	24	41	91	130	109	77	35	10	0	536

Block indicates extent of basic data.

Derived from $V = 0.23760\ D^2H + 9.61017$ for D^2H to 700.
$V = 0.24522\ D^2H + 4.39135$ for D^2H larger than 700.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

Table 4.--Volumes in board feet Scribner Rule per square foot of basal area, lodgepole pines in Colorado and Wyoming

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter 6 inches inside bark
Stump height 0.7 foot

Diameter breast height outside bark (inches)	Number of 16.5-foot logs to 6-inch top									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	- - - - - - - - - - - - - - - - - Board feet - - - - - - - - - - - - - - - - -									
6	63	85								
7	53	75	97	118	140					
8	46	68	90	112	133	155				
9		63	85	107	128	150	172	194		
10		60	81	103	125	147	168	190	212	
11		57	79	100	122	144	166	188	209	
12		55	77	98	120	142	164	186	207	230
13			75	97	119	140	162	184	207	229
14			74	96	117	139	161	184	206	229
15			73	94	116	138	161	183	206	228
16				94	115	138	160	183	205	228
17					115	138	160	182	205	227
18					115	137	160	182	205	227
19					115	137	159	182	204	227
20						137	159	182	204	227
21						137	159	182	204	227
22						136	159	181	204	226
23						136	159	181	204	226
24						136	159	181	204	226

Derived from $V/B = 43.56276\ H + 1761.97609/D^2$ above dotted line.
$V/B = 44.95985\ H + 805.13182/D^2$ below dotted line.

Diameter classes full inch; e.g., 20-inch class includes 20.0 to 20.9.

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

FOLIAR MOISTURE CONTENT OF CHAPARRAL IN ARIZONA:

Accounting for its Variation and Relating it to Prescribed Fires

A. W. Lindenmuth, Jr.,
and James R. Davis[1]

(A Progress Report)

Standard seasonal foliar-moisture (FM) curves, used to prescribe fires in chaparral elsewhere, cannot be used for Arizona chaparral. Day-to-day FM variations during dormancy make seasonal curves unreliable. Mathematical and graphical methods, based on 3 years' data, show promise for a synchronized FM estimating system. Further research is needed, however, to evaluate how short-term fluctuations influence the seasonal trend. Preliminary trend curves presented may help land managers plan burning activities: the manzanita curve for actual burning decisions; the oak curve for programing burning operations.

Key words: Prescribed burning, fuel reduction (forest), forest fuels, forest fire behavior.

Prescribed fire is an efficient tool in brushland management if the land manager has definite objectives and selects specific fire characteristics to accomplish those objectives.

Nearly 20 percent of Arizona's land area is covered with brush, half of which is the evergreen oak type called chaparral. Here, planned fires can be used advantageously to manage chaparral areas for increased water yield or land productivity if the fires can be managed. The most suitable time for prescribed burning in Arizona is the dormant season, September through April.

Seasonal trends or curves,[2] now standard for estimating foliar moisture (FM) for fire activities in chaparral species elsewhere,[3,4,5] cannot be used in Arizona chaparral. FM often increases or

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[1] *Principal Fire Behavior Scientist and Associate Forest Fuels Scientist, respectively, located at Flagstaff, in cooperation with Northern Arizona University; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[2] *Curves that show foliar moisture content of most chaparral reaches a high peak during new growth period, then rapidly drops to a low constant level during dormancy.*

[3] *Buck, C. C. Variation in the moisture content of green brush foliage on the Shasta Experimental Forest during 1938. (Unpublished office report on file at Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.)*

[4] *Fons, Wallace L. Progress report on seasonal variation in moisture content of chaparral foliage on the San Dimas Experimental Forest during 1942. (Unpublished office report on file at Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.)*

[5] *Philpot, C. W. The moisture content of ponderosa pine and whiteleaf manzanita foliage in the central Sierra Nevada. U.S. Forest Serv. Res. Note PSW-39, 7 pp., illus. 1963. (Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif.)*

decreases rapidly within a few days, especially during dormancy; these short-term changes tend to nullify the reliability of a seasonal curve.

This Note reports the progress on a study started in 1964 on how to account for FM variation in Arizona. From 3 years' data, mathematical and graphical methods developed show promise, especially for long-term trends, but day-to-day and seasonal FM changes need to be synchronized into one system.

Three preliminary phases are reported that may help the prescribed fire user estimate FM and interpret fire behavior: (1) significance of seven variables, (2) limitations of eight mathematical equations, and (3) characteristics of FM trends. Two curves are given: the manzanita curve may help in actual burning decisions; the oak, in programing burning operations.

The ultimate goal is a reliable system of estimating and predicting FM in Arizona chaparral regardless of how FM varies. A "reliable" system must be sensitive to day-to-day FM changes, move in the same direction as actual FM, and be as close to actual FM as burning operations require.

Further research will concentrate on estimating and predicting FM, day to day, at midday, during dormancy. Leaf and litter temperatures will be added as variables.

Study Area

The 40-acre Prescribed Fire Experimental Area, where data are collected, is 30 miles east of Prescott, in the largest concentration of chaparral in Arizona. This typical chaparral area, at 4,700 feet elevation and with thin, poorly developed granitic soils, is on the Prescott National Forest. Temperatures are mild year long.

Shrub live oak (Quercus turbinella Greene) is the dominant species, with frequent occurrences of pointleaf manzanita (Arctostaphylos pungens H.B.K.).

Annual precipitation averages 16.5 inches. Per-month averages are 0.40 inch for the dry months (May, June, October), 2.65 for the wet months (July, August, December), and 1.25 for the remainder. Wide departures from average are commonplace.

Winter precipitation is transient snow or low-intensity rain, with little runoff. High-intensity rains, with considerable runoff, are common the rest of the year. Precipitation exceeds evapotranspiration 1 out of 4 months.[6] Practical surpluses occu however, only during winter—nearly every ye in December and every fourth year in January ar February.

Methods

Two chaparral species were selected for stud shrub live oak because it is the dominant specie and is drought resistant; pointleaf manzanita becaus it frequently occurs with oak and is droug sensitive.

Species and weather data were collected fo 3 years, beginning in 1964, during growth (Ma August) and dormant (September-April) periods. T eliminate any influence of intermittent weath changes, FM analyses were based on samples co lected on clear days (continuous sunlight for 1 hou preceding sampling). Data were insufficient fo separate analyses of partly cloudy and cloudy days these data will be added in further studies.

Stepwise multiple linear regression and princip component analysis were selected for the initi mathematical analysis.

Sampling Procedure

Permanent transects represent the total population of the study site. Sample leaves were picke once or twice a week. Each day's sample was take from 10 randomly selected plants, and include all leaf conditions—green, dead, and dying—in proportion to the total population. The collector estimated proportions on each plant: if a plant showe approximately 10 percent dead leaves based o sample leaf-twig counts, he picked one dead an nine green leaves.

Leaves were picked between 12:30 and 1:0 p.m. (to neutralize diurnal variation), in full sunlight on clear days and at random on other days, and placed in friction-top metal cans. Each day's sample—15 grams for oak, 30 for manzanita—were weighed on the sampling site, and stored in the collection cans until taken to the laboratory, where they were ovendried weekly at 105° C.

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[6] *According to the system of estimatin available moisture given in: Thornthwaite, C W. An approach toward a rational classificatio of climate. Geog. Rev. 38: 55-94. 1948.*

Variables

Input variables were:

X_2 = Number of days since more than 0.20 inch precipitation
X_3 = Air temperature
X_4 = Drought Index[7]
X_5 = Relative humidity
X_6 = Partial vapor pressure
X_7 = Wind velocity
X_8 = Net radiation

Weather measurements, taken at the sample site at 1:00 p.m., met or exceeded the accuracy specified for rating fire danger.

Equations

Eight regression equations were tested to calculate FM. Equations 1, 3, 5, and 7 included all years and all variables except net radiation during the growing period; equations 2, 4, 6, and 8 included only those variables that appeared to contribute to FM content. Curvilinearity was not adjusted.

Results and Discussion

Tables 1 and 2 show how the variables influenced the FM content of oak and manzanita. Figures 1 and 2 show the FM variation during the dormant season for each species: figure 1, the actual variation each year; figure 2, the 3-year average variation.

In all years, the actual FM pattern for oak differed from manzanita, even though the plants were

REGRESSION EQUATIONS

MANZANITA

Dormant:

$$R^2 = 0.463 \quad Y = 114.129 - 0.199X_2 - 0.348X_3 - 0.113X_4 - 33.240X_5 + 28.870X_6 + 0.144X_7 + 6.277X_8 \tag{1}$$

$$R^2 = 0.419 \quad Y = 111.598 - 0.256X_2 - 0.223X_3 - 0.083X_4 - 19.733X_5 \tag{2}$$

Growing:

$$R^2 = 0.234 \quad Y = 108.643 - 0.306X_2 + 0.060X_3 - 0.372X_4 - 0.073X_7 \tag{3}$$

$$R^2 = 0.229 \quad Y = 110.991 - 0.315X_2 - 0.344X_4 \tag{4}$$

OAK

Dormant:

$$R^2 = 0.301 \quad Y = 76.438 - 0.062X_2 - 0.049X_3 - 0.024X_4 - 20.653X_5 + 31.979X_6 + 0.200X_7 + 6.137X_8 \tag{5}$$

$$R^2 = 0.262 \quad Y = 66.303 - 0.089X_2 + 0.085X_3 + 0.307X_7 + 5.360X_8 \tag{6}$$

Growing:

$$R^2 = 0.422 \quad Y = 69.990 + 0.204X_2 + 0.369X_3 - 0.287X_4 + 2.755X_5 + 4.431X_6 + 0.294X_7 \tag{7}$$

$$R^2 = 0.397 \quad Y = 73.800 + 0.204X_2 + 0.317X_3 - 0.246X_4 + 0.258X_7 \tag{8}$$

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[7] *Based on wintertime precipitation, current precipitation, and air temperature; derived from moisture depletion and accretion in the upper foot of bare soil. See: Lindenmuth, A. W., Jr. Development of the 2-index system of rating forest fire danger. J. Forest. 59: 504-509. 1961.*

Table 1.--Correlation coefficients (r) that show significance between foliar moisture and individual variables tested, and regression coefficients (R) after adjustment for collinearity by principal components (importance of variable indicated by size and the direction by the algebraic sign)

Species, period, and coefficients	Days since precipitation X_2	Air temperature X_3	Drought Index X_4	Relative humidity X_5	Partial vapor pressure X_6	Wind velocity X_7	Net radiation X_8
GROWING PERIOD							
SHRUB LIVE OAK:							
Correlation (r)							
1964	+0.432*		+0.576**			-0.446*	(1)
1965							
1966							
All		+0.433**		-0.291*		+.260*	(1)
Regression (R)	+3.04	+20.58	-16.45	+2.60	+10.72	+3.91	(1)
POINTLEAF MANZANITA:							
Correlation (r)							
1964			-.369*				(1)
1965	-.715**		-.781**				
1966				-.412*	-.435*		
All	-.356**		-.442**				(1)
Regression (R)	-17.10	-4.42	-14.11	-2.54	-6.18	+3.02	(1)
DORMANT PERIOD							
SHRUB LIVE OAK:							
Correlation (r)							
1964-65	-.470*		-.644*				+0.782**
1965-66	-.359*				+.428**		+.389*
1966-67							
All	-.248*	+.265*			+.259*	+.276*	+.365**
Regression (R)	-9.57	+7.13	-.10	-3.22	+4.89	+2.53	+12.06
POINTLEAF MANZANITA:							
Correlation (r)							
1964-65	-.566**		-.606**				
1965-66	-.554**	-.594**			-.365*		
1966-67	-.538**		-.673**				
All	-.457**	-.411**	-.498**		-.251*		
Regression (R)	-22.10	-15.26	-20.01	-1.55	-13.12	+11.00	+14.47

* Significant at .05 level.
**Significant at .01 level.
[1]Not measured in 1964 growing period.

intermixed (fig. 1). Species composition, then, should be evaluated in fire operations since it is an important variable in estimating FM of mixed fuels.

The FM pattern for each species varied from year to year; abrupt increases in FM of both species usually coincided with precipitation, but not always.

Manzanita was more drought sensitive than oak; manzanita FM dropped severely during fall droughts, but recovered rapidly following precipitation (fig. 1).

Trend curves for the three combined dormant seasons accounted for 79 percent of the variation in manzanita FM, and 52 percent in oak. The average FM trends (fig. 2) indicate that the manzanita curve can be helpful on clear days for actual burning decisions; the oak curve, over longer periods for work programing.

Significance of Variables

FM was significantly correlated with each variable tested (table 1). The closest simple relation

Table 2.--Variation in moisture content of leaves of shrub live oak and pointleaf manzanita accounted for by the independent variables tested, from stepwise regression analysis

Growing period					Dormant period				
Year	Shrub live oak		Pointleaf manzanita		Year	Shrub live oak		Pointleaf manzanita	
	Variable	R^2	Variable	R^2		Variable	R^2	Variable	R^2
1964[1]	4	0.332**	4	0.136	1964-65	8	0.612**	4	0.367**
(n=27)	47	.406**	46	.249*	(n=22)	84	.677**	42	.407**
	475	.419**	463	.334*		847	.707**	427	.412*
	4753	.433*	4635	.343*		8475	.731**	4275	.417*
	47532	.455*	46357	.348		84753	.738**	42756	.421
	475326	.456*	463572	.349		847536	.762**	427563	.437
			(2)			8475362	.767**	4275638	.445
1965	7	.082	4	.610**	1965-66	6	.183**	4	.371**
(n=19)	76	.152	42	.663**	(n=40)	62	.268**	48	.557**
	768	.258	428	.717**		624	.314**	483	.640**
	7684	.302	4286	.745**		6247	.326**	4832	.671**
	76843	.367	42865	.746**		62473	.341*	48326	.682**
	7643	.367	428657	.746**		624735	.343*	483265	.686**
	76432	.484	4286573	.750**		6247358	.345*	(2)	
	764328	.548	428673	.748**					
	7643285	.551							
1966	3	.138	6	.189*	1966-67	5	.067	4	.453**
(n=25)	38	.216	64	.365**	(n=25)	58	.088	48	.648**
	382	.265	642	.429**		587	.092	482	.672**
	3826	.279	6423	.438*		5872	.095	4826	.679**
	38265	.296	64237	.449*		58724	.098	48267	.680**
	382657	.314	642378	.450		(2)		482675	.681**
	3826574	.316	6423785	.450				482653	.683**
								4826537	.683**
All[1]	3	.187**	4	.195**	All	8	.133**	4	.248**
(n=71)	34	.305**	42	.228**	(n=87)	87	.184**	42	.326**
	347	.365**	423	.233**		873	.218**	423	.378**
	3472	.397**	4237	.234**		8732	.262**	4235	.419**
	34726	.420**	(2)			87325	.268**	42358	.440**
	347265	.421**				873256	.296**	423586	.460**
						8732564	.301**	4235867	.462**

* Significant at .05 level.
**Significant at .01 level.
[1] Net radiation (X_8) omitted; measurements were not made during the 1964 growing period.
[2] F-level of remaining variables insufficient for additional computation.

ship was manzanita FM on Drought Index; during the 1965 growing period the Drought Index range accounted for 61 percent (r^2) of the variation (table 1).

The most variation accounted for by all variables (table 2) was for oak during the 1964-65 dormant period—77 percent (R^2).

The importance of each variable, in the direction of the algebraic sign, is indicated by the component analysis (R, table 1). The algebraic signs were consistent for Drought Index, wind velocity, and net radiation; days-since-precipitation signs were consistent where this variable was important.

In accounting for FM variations, Drought Index ranked important in three of four species-period categories; net radiation in the two for which measurements were available. Under some conditions, days-since-precipitation and air temperature were important variables. Partial vapor pressure was moderately important in two categories, wind velocity was relatively unimportant, and relative humidity was least important of all variables tested.

The algebraic signs of some coefficients may seem questionable; for example, the positive sign for net radiation indicates that FM increased when radiation increased, and vice versa. Collinearity could have caused this, but the data do not support that interpretation. Net radiation carried the positive sign through 50 of 54 steps in the regression analysis; the four exceptions were steps where net radiation entered late and was relatively unimportant. Also, regression with principal components showed

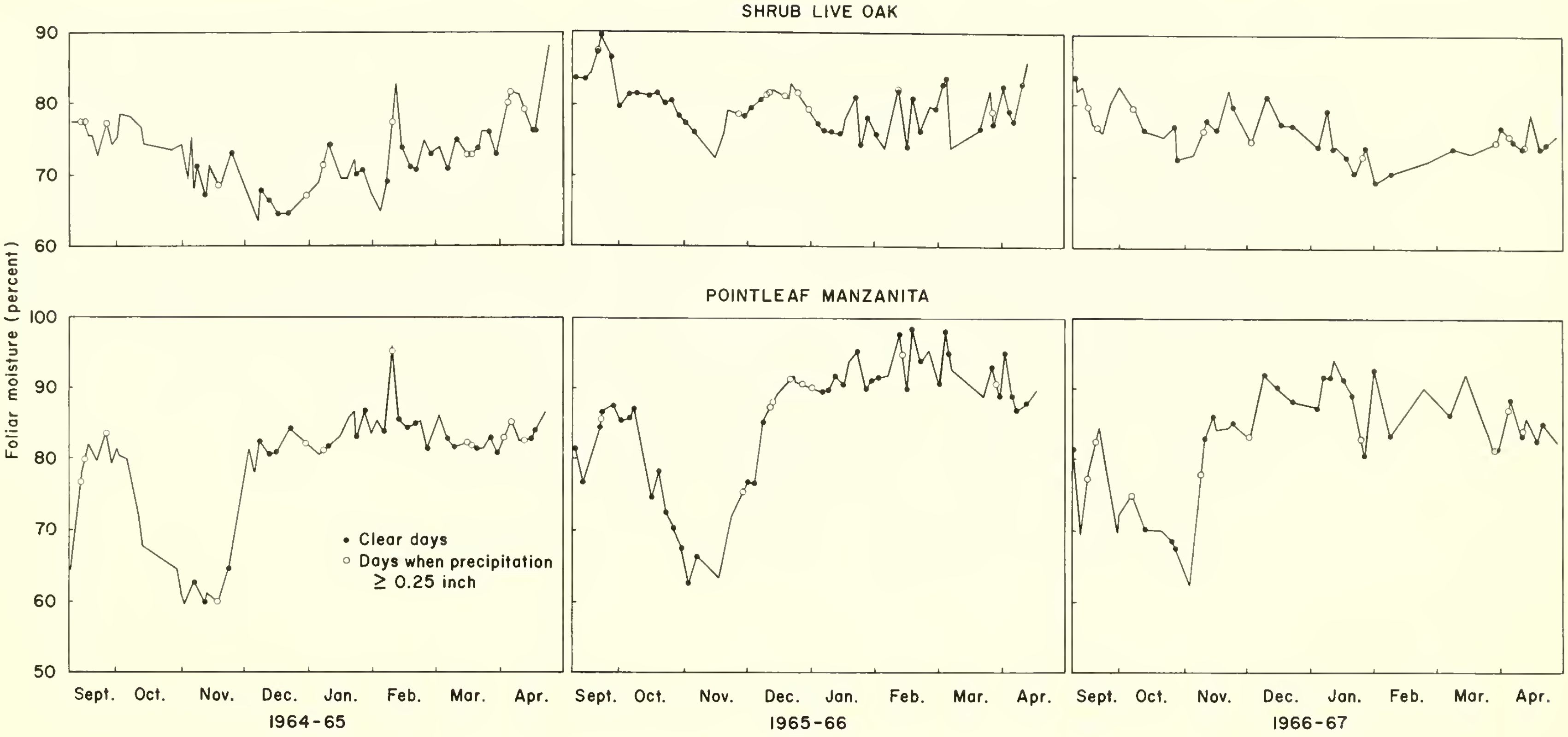

Figure 1.--Actual variations in foliar moisture (FM) of shrub live oak and pointleaf manzanita for individual dormant seasons, September 10 - April 30, 1964-67, Prescribed Fire Experimental Area, Prescott National Forest, Arizona.

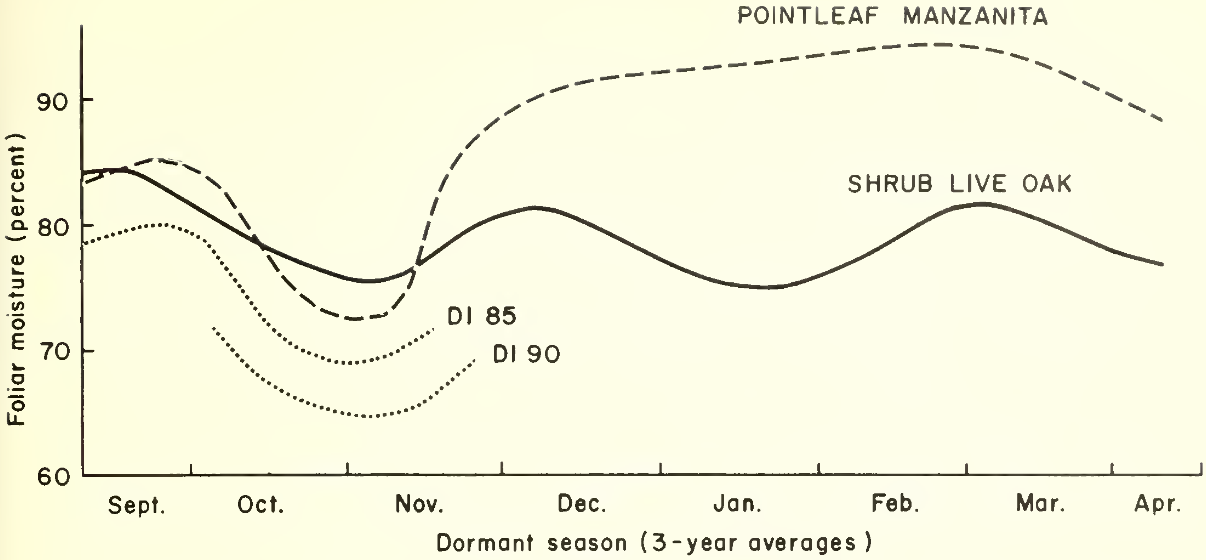

Figure 2.--Average values (trends) of foliar moisture of shrub live oak and pointleaf manzanita for three dormant seasons, September 10 - April 30, 1964-67, Prescribed Fire Experimental Area, Prescott National Forest, Arizona. Use manzanita curve for actual burning decisions (short-term). Use oak curve for programing burning operations (long-term). If Drought Index (DI) is 85 or more, follow dotted lines for manzanita. If carryover leaves exceed half of total leaf population, between November 16 and May 1, deduct 5 percent from oak and 9 percent from manzanita FM estimates.

a positive coefficient. The data strongly indicate that the algebraic sign represents a real relationship, but additional research is needed before explaining the relationship in terms of plant physiology.

For air temperature and partial vapor pressure, the signs were negative for manzanita and positive for oak. In the regression analysis, the signs for temperature and pressure, related by definition, changed more often than they did for net radiation. Perhaps collinearity with other variables caused the difference in signs by species, but the signs might indicate real effects. Since manzanita is drought sensitive and oak is drought resistant, air temperature and partial vapor pressure might affect their FM differently.

Limitations of Mathematical Equations

The regression equations included seven variables, for 3 years' data, during dormant and growing seasons. The contribution of each variable ranged widely, often dramatically. For the 3-year period, the calculated FM variation was less than half the actual variation, so the equations cannot be used to plan prescribed fires.

For individual periods, however, the equations accounted for up to 77 percent of the FM variation, so they may be useful for short-term planning. Data were insufficient to explore that possibility.

The equations might be improved if they were adjusted for curvilinearity. Graphics showed that all simple relationships were curvilinear, especially FM on Drought Index where all effects ranged in the upper 20 percent of the DI.

Characteristics of FM Trends

Inherent weaknesses of both the trend curves and the composite mathematical equations are that (1) estimates are reasonable only when weather conditions approximate those on which the curves or equations are based, (2) day-to-day changes in FM are not reflected, and (3) the actual FM covers a much wider range than average FM. The larger the number of varied seasons used in calculating trends, the flatter the composite trend; for example, compare the actual FM traces (fig. 1) with the relatively flat, smooth trend curves (fig. 2), especially for oak. Equations behave similarly.

The correlation coefficient for estimated and actual FM is better for manzanita (0.8879) than for oak (0.7203).

The general downward trend in oak FM from September through January, and the gradual climb from February through April (fig. 2) corresponds with similar trends in net radiation and air temperature. Both of these rate as important variables for oak FM (R, table 1). Other variables contributed the interspersed mounds and depressions.

Drought Index and the manzanita FM trend are inversely related. Figure 2 shows how FM dips in the usually dry fall months, rises rapidly in December, then slightly declines toward the end of the dormant season. Because of the strong influence of Drought Index, and its wide variance in the fall, supplemental curves (dotted lines, fig. 2) for October and November improve estimates of manzanita FM.

Manzanita FM was more consistently correlated with the variables tested during individual years. Four variables accounted for 67 percent of FM variation in manzanita during the 1965-66 dormant period (table 2).

Manzanita FM estimates correlate better than oak because (1) the manzanita FM range is twice that for oak, and (2) the widest variation in manzanita FM occurs fairly regularly in October and November during drought conditions, which are scaled by Drought Index.

Leaf mix—the proportion of old and new leaves in the population—varies from year to year. Sometimes carryover leaves persist for an entire dormant period, and may account for unusual year-to-year changes in the influence of variables.

In 1964, carryover was high and few new leaves grew; in 1965, carryover was negligible and an abundant new leaf crop matured early. In 1966, however, the transition from growth to dormancy prolonged all summer; the carryover was light and a relatively small new crop of leaves matured late.

The 1964-65 FM values, noticeably low (fig. 1), may be the result of a large carryover of old leaves. FM estimates may be more accurate, then, if compensating adjustments are made. When carryover leaves make up half or more of the leaf population, the suggested adjustment, from November 16 to May 1, is to deduct 5 percent from oak and 9 percent from manzanita FM estimates (fig. 2).

Conclusions

1. Each input variable tested significantly indicated foliage moisture (FM) in at least one species-period category.
2. The influence of variables differed by species periods, and years, with some dramatic changes
3. Manzanita, the more drought-sensitive plant, was more highly and consistently correlated with the variables tested during individual years. The manzanita trend curve can be helpful for estimating FM on clear days for actual burning decisions, in central Arizona and climatically similar areas, when the seasonal precipitation pattern is normal; otherwise, estimates are too high during dry periods and too low during wet periods
4. Oak, the more drought-resistant plant, seemed to show better correlation for a longer period The oak trend curve, although less help for estimating FM day by day, reflects average levels for clear days during normal seasonal weather in central Arizona and climatically similar areas, and can be useful in programing burning.
5. Preliminary research points the way toward an objective system for estimating FM in Arizona chaparral. At least 3 years of additional intensive data must be accumulated and analyzed, by short periods, before long-term and short-term variations in FM can be accounted for reliably.
   a. Day-by-day sampling is needed to chart trends accurately, and to rapidly build up a large number of observations suitable for analyses by short periods.
   b. Sampling must be done by identifiable leaf conditions (green vs. brown) and age (carryover leaves vs. current-year leaves).
   c. Analyses should be made separately for clear, partly cloudy, and cloudy days by biweekly periods, to reveal the influence of each important variable with respect to time, physiological condition of plants, and magnitude of measured variables. Data should then be reduced to trends with supplementary provisions for day-by-day corrections.
   d. Two variables should be added: leaf temperature and litter temperature. Since little is known about leaf and litter temperatures in Arizona chaparral, these measurements may help clarify the effects of other variables such as net radiation, air temperature, Drought Index, and wind. Leaf temperatures are measured by 0.010-inch-diameter stainless steel sheathed thermocouples inserted into living leaf tissue, and changed weekly to new leaves. Litter temperatures are measured by 0.065-inch-diameter thermocouples inserted 0.50 inch below the litter surface.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-159

REST SERVICE
. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fire Stimulated Aspen Sprouting in a Spruce-Fir Forest in New Mexico

David R. Patton[1] and Herman D. Avant[2]

Data from a burned area in the spruce-fir type, the Walker Burn, indicate that burning significantly increases aspen density for about 4 years. After that, the number of stems per acre declines, and the aspens begin to grow out of reach as browse for elk and deer.

(KEY WORDS: Populus tremuloides, wildlife food plants, forest fire behavior)

In southwestern United States, one of the preferred foods for deer and elk is aspen stems and leaves.[3,4]

A wildfire in April 1963 presented an opportunity to study fire as a technique to stimulate aspen sprouting. The fire, named the "Walker Burn," burned over 300 acres in the spruce-fir type on the Santa Fe National Forest, New Mexico (fig. 1).

The spruce-fir type at the Walker Burn had an overstory of quaking aspen (Populus tremuloides Michx.), Engelmann spruce (Picea engelmannii Parry), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), and ponderosa pine (Pinus ponderosa Lawson).

Figure 1.--Location of the 300-acre Walker Burn on the Santa Fe National Forest in New Mexico.

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[2] District Ranger, Walnut Creek District, Prescott National Forest, U. S. Dep. Agr., Forest Serv., Prescott, Ariz.

[3] Wallmo, O. C., and McCulloch, Clay. Influence on carrying capacity of experimental water conservation measures. Job Completion Rep. W78R7-WP5-J7, 12 p., illus. In Wildlife research in Arizona, 1962. Ariz. Game and Fish Dep. [Phoenix, Ariz.]

[4] Lang, E. M. Elk of New Mexico. N. Mex. Dep. of Game and Fish Bull. 8, 33 p. 1958.

Understory vegetation consisted mainly of willow (*Salix* spp.), New-Mexican rose (*Rosa neomexicana* Cockrell), Oregongrape (*Mahonia repens* (Lindl.) G. Don), geranium (*Geranium* spp.), strawberry (*Fragaria* spp.), shrubby cinquefoil (*Potentilla fruticosa* L.), filaree (*Erodium cicutarium* (L.) L'Her.), sedge (*Carex* spp.), and nodding brome (*Bromus anomalus* Rupr.).

Deep litter on the area helped maintain a hot ground fire that consumed all the understory hardwoods and conifers. Heat completely defoliated the overstory; a few trees have recovered, but many dead snags remain.

Research on the influence of fire on aspen has shown sprouting to be related to fire intensity. "A moderate burn, one which kills the tree canopy and undergrowth and eliminates the litter and part of the duff, will most effectively stimulate suckering. Lesser intensities of burning will produce less dense and vigorous suckers."[5]

This Note reports how fire stimulated aspen sprouting, and how forest managers might use fire to provide aspen browse for deer and elk.

Methods

In August 1964, 18 months after the fire, 1 acre on the Walker Burn was fenced to exclude cattle. Twenty 0.01-acre plots were established within the burned area; 10 inside the exclosure and 10 outside. Aspen sprouts were photographed and counted five times on each of the 20 plots—September 1964, and each June, 1965 through 1968.

Results

Fire significantly increased the number of aspen sprouts on the Walker Burn. The 5-year average density was 12,960 sprouts per acre on the burned area, compared with 100 in the adjacent unburned forest, and 200 to 500 in a similar spruce-fir type in Arizona (table 1).[6,7]

Table 1.--Number of aspen sprouts per acre on the Walker Burn, Santa Fe National Forest, New Mexico, compared with unburned aspen areas in the spruce-fir type

Date data were collected	Walker Burn			Unburned areas		
	Inside exclosure	Outside exclosure	Average	Adjacent to Walker Burn[1]	Apache National Forest, Arizona	
					Aspen groves	Willow Creek
	- - - - - - - - - -	- - - - - - - -	- Number per acre -	- - - - - - - -	- - - -	- - -
1964 (September)	10,500	13,100	11,800	100	--	--
1965 (June)	12,600	15,100	13,850	--	--	--
1966 (June)	13,700	15,400	14,550	--	--	--
1967 (June)	12,100	13,400	12,750	--	200	--
1968 (June)	11,200	12,500	11,850	--	--	--
1969 (August)	--	--	--	--	--	500
Average	12,020	13,900	12,960	100	200	500

[1] Estimated--no actual counts made.

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[5] *Horton, K. W., and Hopkins, E. J. Influence of fire on aspen suckering. Dep. Forest., Can. Publ. 1095, 19 p., illus. 1965.*

[6] *Reynolds, Hudson G. Aspen grove use by deer, elk, and cattle in southwestern coniferous forests. U.S.D.A. Forest Serv. Res. Note RM-138, 4 p., illus. 1969. (Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.)*

[7] *Patton, David R. Deer and elk use of a spruce-fir type before and after a timber harvest. 1969. (Unpublished data on file at Rocky Mt. Forest and Range Exp. Sta., Tempe, Ariz.)*

Livestock and wildlife use on the burned area did not significantly affect aspen density; the number of sprouts was similar inside and outside the exclosure.

Sprouts increased on the burned area each year to 1966 when the density was 14,550 per acre. Then the number of stems began to decrease until 1968 when the per-acre density was 11,850.

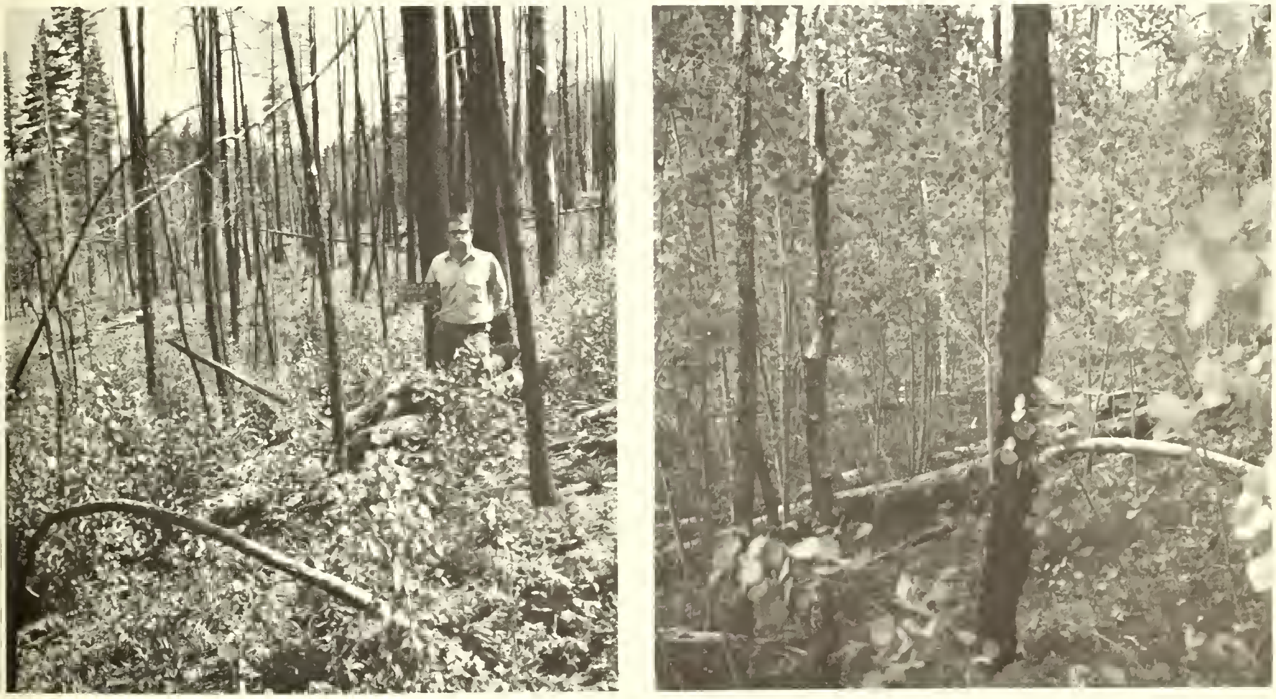
In 1964, the aspen sprouts were less than 3 feet tall, so elk and deer could browse them easily. By June 1968, however, the sprouts were 8 to 10 feet tall and getting out of reach as a food supply (fig. 2).

Conclusions

Although data are from only one burned area in the spruce-fir type in the Southwest, the 300-acre Walker Burn, indications are that:

1. Fire stimulates aspen sprouting and may be an effective tool in producing browse for deer and elk.
2. Aspen-sprout density increases for about 4 years following a fire, then the number of stems per acre begins to decrease.
3. Six to eight years after a fire, the majority of aspen sprouts may be 8 to 10 feet tall and will no longer be in reach for deer and elk to use as browse.

Figure 2.--Aspen sprouts after 1963 wildfire in spruce-fir type, Santa Fe National Forest, New Mexico (same camera point):



September 1964--
Aspen browse not over 3 feet tall; plentiful, tender, and succulent food for deer and elk.

June 1968--
Aspen sprouts, 8 to 10 feet tall; leaves and twigs nearly out of reach as a food supply.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-160

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Storage Does Not Affect Crude Protein Content of Forage Samples

Floyd W. Pond and Henry A. Pearson[1]

Storage of forage samples for 15 months prior to proximate analysis had no apparent effect on crude protein. (KEY WORDS: Plant proteins, forage plants, range management)

Forages are frequently collected from rangelands d stored in containers for proximate analysis some future date. The effect of prolonged rage on chemical composition, especially crude otein, has frequently been discussed but has not en reported. Since crude protein is of major portance in assessing nutritive values of range rages, effect of storage should be substantiated.

Methods

In early 1963, 34 forage samples were collected the Sierra Ancha Experimental Forest near Rooselt Lake in central Arizona. These samples were endried at 70° C. for 24 hours, ground, and aced in screw-cap jars. These jars were stored on elves for a short time before a portion of each mple was analyzed for crude protein. The remainr of each sample was retained in the sealed s under normal room temperature and light conions until analyzed for crude protein by a different laboratory in September 1964. Although separate laboratories made the two analyses, both followed AOAC[2] methods. Dietz and Curnow[3] showed that most analyses from different laboratories were comparable.

Results and Discussion

Average crude protein content of the 34 samples was 7.23 percent when analyzed soon after collection and 7.41 percent after prolonged storage. The largest difference between paired samples was 2.5 percent; 19 of the 34 pairs were within 0.2 percent of each other. After prolonged storage, 27 of 34 times the analysis of crude protein content was equal to or greater than results from earlier analyses. Standard error of difference was only 0.0896 and "t" was 1.965. Since this analysis showed no significant change in crude protein content between the two analyses, a 15-month delay in analyzing for crude protein should not significantly affect the results.

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[1] *Range Scientists, respectively, located Flagstaff, in cooperation with Northern izona University; central headquarters are intained at Fort Collins, in cooperation th Colorado State University. Pearson is w located at Southern Forest Experiment Staon, Pineville, Louisiana 71360.*

[2] *Association of Official Agricultural Chemists (AOAC). Official methods of analysis. Ed. 9, 832 p. Washington, D. C. 1960.*

[3] *Dietz, Donald R., and Curnow, Richard D. How reliable is a forage chemical analysis? J. Range Manage. 19: 374-376. 1966.*

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U S D A FOREST SERVICE
RESEARCH NOTE RM-161

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Cacodylic Acid Field Tested for Control of Mountain Pine Beetles in Ponderosa Pine

John F. Chansler,[1] Donn B. Cahill,[1] and Robert E. Stevens[2]

In an operational-scale field test, cacodylic acid (dimethylarsenic acid) was highly effective in preventing brood development of mountain pine beetle (Dendroctonus ponderosae Hopk.) in ponderosa pines (Pinus ponderosa Laws.) that had been infested about 2 weeks before treatment. Beetles infesting trees that had been treated with acid prior to the attack period were also unable to produce brood. Overall treating costs of $2 per tree were substantially lower than other direct-control methods. (KEY WORDS: Cacodylic acid, herbicides, insect control, Scolytidae, Dendroctonus ponderosae, Pinus ponderosa)

Cacodylic acid (dimethylarsenic acid), an herbicide, has shown promise in several recent experiments as a chemical control for bark beetles. A small-scale test by Chansler and Pierce[3] indicated it could cause satisfactory mortality against the mountain pine beetle (Dendroctonus ponderosae Hopk.) in ponderosa pine (Pinus ponderosa Laws.).

Introduced into the sap stream of a tree, cacodylic acid either kills beetles outright, makes the environment unsuitable for them, or both. Acid-treated green trees are attractive to beetles under certain conditions, and this characteristic has been used in attempts to reduce beetle populations by setting up fatal "attractant centers." Postflight applications, in which newly infested trees are treated, have also been tried.

The field test reported here was conducted in the northern Black Hills of South Dakota, about 10 miles southwest of Spearfish. The stand was primarily dense second-growth ponderosa pine about 90 years old, undergoing heavy attack by mountain pine beetles.

The objectives of the study were to:

1. Test a preflight acid treatment for its effectiveness in attracting beetles and killing them in place.
2. Test a postflight treatment in attacked trees for its effectiveness in killing beetles in place.
3. Obtain cost estimates for both treatments.

Methods

An area of about 5,000 acres known locally as Higgins Gulch was selected for a test site.

During the week of July 22, 1968, about 3 weeks prior to the normal mountain pine beetle mass attack period, 112 trees, mostly culls, were treated. These trees were then considered "pre-

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[2] *Principal Entomologist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[3] *Chansler, John F., and Pierce, Donald A. Bark beetle mortality in trees injected with cacodylic acid (herbicide). J. Econ. Entomol. 59: 1357-1359. 1966.*

disposed" to attack. Treatment consisted of frilling the entire circumference of the tree trunk about 8 inches above groundline and applying full-strength Silvisar 510[4] from a squeeze bottle to the frilled area. About 2 ounces of material was used on each tree. Approximately 10 days after beetle flight, the area was carefully cruised and all successfully attacked trees found (895) were treated in the same manner as the predisposed trees. The results were checked briefly early in 1969, and were evaluated in detail on June 4 and 5. The final evaluation consisted of sampling typical trees throughout the treated area that received either of the two acid treatments, and several untreated but infested check trees. A series of six 6- by 6-inch bark samples was removed from each tree, one each from the north and south sides at (1) breast height, (2) 5 feet below the upper limit of the infestation, and (3) midway between the other two samples. Numbers of attacks, inches of egg gallery, and numbers of living insects were recorded from each sample. Diameter at breast height and the infested height of each tree were also recorded.

Results

The results of both treatments are presented in table 1.

The preflight treatment, including $53 aircraft rental for detection purposes, cost just over $400, or about $3.60 per tree. Labor, mileage, and materials (acid) are included. The postflight treatment, involving a combined 100 percent cruise of the area and treatment of infested trees found, cost about $1,000, or about $1.15 per tree.

Discussion

Preflight Treatment

According to the crews making the postflight treatment, 85 percent of the trees that had been predisposed to attack were successfully attacked, and 66 percent of all subsequently attacked groups included predisposed trees.

In the final evaluation, we had difficulty distinguishing predisposed trees from infested trees treated after the mass attack, and in determining which of the predisposed trees had been successfully attacked. The trees we could identify were only attacked about one-half as heavily as green trees. We did not feel that these trees acted as especially efficient "attractant centers," but the experiment did not permit a quantitative evaluation of this factor. More study is needed before cacodylic

Table 1.--Effect of preflight and postflight cacodylic acid treatments against mountain pine beetles, South Dakota, 1968-69

Treatment	Sample trees			Mountain pine beetles			
	Size of sample	Average d.b.h.	Average height of beetle infestation	Average per square foot			Total liv insects in sample
				Attacks	Length of egg gallery	Live insects	
	Number	Inches	Feet	Number	Inches	Number	Number
Preflight	8	11.5 ± 1.3	24.7 ± 9.7	4.4 ± 7.6	17 ± 18.4	0	0
Postflight	10	13.1 ± 2.1	24.3 ± 6.1	7.2 ± 4.2	47 ± 35.6	0.1	5
No treatment (Check)	4	14.6 ± 3.9	24.3 ± 4.7	7.0 ± 4.4	87 ± 37.6	72.5	435

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[4] *Trade name for a solution manufactured by the Ansul Company, Marinette, Wis., that contains the equivalent of 5.7 pounds of cacodylic acid per gallon. Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

cid can be considered useful as a beetle attractant n ponderosa pine. This study will need to center n such questions as timing, concentrations of the aterial, and distribution of treated trees.

ostflight Treatment

The postflight treatment was highly successful. ssentially no live insects were recovered from these rees, although attack density was comparable to that n untreated infested trees. Egg gallery length was ubstantially reduced, so total oviposition was preumably less. In most instances larval galleries had ot been started, although a few larvae had proressed up to 1 inch before dying. Because this ndicates the acid may be adequately transported ome time after attack, more latitude may be availble in timing the treatment. This will be investiated in future studies.

The number of check trees used to evaluate the esults is admittedly small. Data from them are onsistent with those generally obtained from norally infested trees, however, and are considered eliable. The fact that all or practically all insects ere killed in both acid treatments made it unnecesary to account for differences in aspect or height f samples.

We conclude from the results that the acid treatent about 10 days following attack was highly ffective in killing beetles. Similar results could probably be achieved elsewhere in the central Rockies where infestation conditions are comparable.

On the basis of this test, we feel that a series of carefully controlled pilot projects should be conducted against mountain pine beetles in ponderosa pine. Since cacodylic acid is properly registered for use as an herbicide, and its method of use here is similar, we see no unusual hazards. Until the application timing is further refined, treatments should probably be made within the period of 5 to 20 days following mass attack, which usually occurs about August 15 [5] in the Black Hills and central Rockies. Since timing in relation to the mass attack is especially important, a few infested trees in areas proposed for treatment should be caged and emergence noted to determine if the mass attack period is much different from normal.

Other aspects of a direct-control project, such as selection and layout of control areas and careful spotting to insure that all trees are treated, do not differ from those encountered with conventional treating methods. The limited time available for applying cacodylic acid is critical, and intensive preplanning will be required.

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[5] *McCambridge, W. F. Emergence period of Black Hills beetles from ponderosa pine in the central Rocky Mountains. U. S. Forest Serv. Res. Note RM-32, 4 p., illus. 1964. (Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo. 80521)*

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U.S.D.A. FOREST SERVICE
RESEARCH NOTE RM-162

REST SERVICE
. DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Emergence and Survival of Winterfat Seedlings from Four Planting Depths

H. W. Springfield[1]

Winterfat (Eurotia lanata) fruits and seeds from three sites in New Mexico were planted at 0, 1/8-, 1/4-, and 1/2-inch depths in soils from those sites. Seedling emergence and survival were highest from surface planting, and decreased with planting depth to none at 1/2-inch depth. Threshed seeds showed advantages over fruits, especially for surface planting. The results suggest seeds should be planted on or near the surface when soil moisture is between field capacity and saturation. (KEY WORDS: Eurotia lanata, winterfat, range management, forage plants, plant physiology)

Winterfat (Eurotia lanata (Pursh) Moq.) has good ootential for revegetation because of its drought resistance, palatability, and nutritive value. Attempts to establish this species by direct seeding in New Mexico, however, have given erratic results.

Many factors probably affect the germination and establishment of winterfat, but past research ndicates depth of seeding is an important consideration. Wilson (1931) reported much of the seed on the soil surface will germinate if there are several days of wet weather during fall and winter, and recommended covering the seed no more than 1/4 inch deep. Hilton (1941) reported no seedling emergence from seeds planted 1/2 nch or deeper under high soil temperatures. Riedl et al. (1964) obtained good stands from planting seed 1 to 2 inches deep in old furrows on sod in Wyoming. Other trials in Wyoming, however, showed better emergence from 1/4 inch than from 1/2- or 3/4-inch-deep plantings (Statler 1967).

This study was undertaken to determine, for mportant soil types and seed sources in New Mexico, the effect of planting depths on seedling emergence and survival of winterfat.

Methods

Three sources of seed were planted at four depths in three different soils in July 1968 (table 1). The soils were obtained from the same sites as the seeds. Whole fruits and threshed seeds were compared. Tests were made in plastic trays, which were completely randomized in a 3 x 3 x 2 factorial design. Each combination of soil, seed source, and fruit or seed was planted in a single tray (fig. 1). Depth of planting was introduced as a split-plot feature with fruits or seeds planted at all four depths in each tray. Fruits and seeds were planted at the rate of 20 viable seeds per 6-inch row. The number of fruits planted varied by source according to the percentage that contained seeds.

Depths of seeding were surface, 1/8 inch, 1/4 inch, and 1/2 inch. The experiment was conducted outdoors on a north exposure where there was protection from rain and direct sunlight, but no control of temperature or wind. A very light layer of soil was spread over seeds and fruits planted on the surface to prevent the wind from blowing them out of the rows.

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[1] *Range Scientist, located at Albuquerque, n cooperation with the University of New Mexi- o; central headquarters maintained at Fort Collins, in cooperation with Colorado State niversity.*

Table 1.--Data on three soils and sources of winterfat seed, collected in New Mexico, October 1967

Name and location of collection site	Elevation	Annual precipitation	Soils data					Seed data			
			Texture	pH	Moisture			Fruits	Seeds	Filled fruits	Fruit per row
					Saturation	1/3 bar	15 bar				
	Feet	Inches			- - Percent - -			Number per pound		Percent	Numbe
Wingate (W): 18 miles east of Gallup	7,400	12	Clay	7.8	46.8	18.9	11.9	70,700	212,600	80	25
Quail Restoration Area (QRA): 8 miles west of Santa Fe	6,400	12	Sandy loam	7.1	30.6	11.8	5.3	78,700	208,200	91	22
Silver Hill (SH): 8 miles west of Magdalena	6,900	11	Loamy sand	7.6	27.4	6.4	3.6	68,800	209,700	88	23

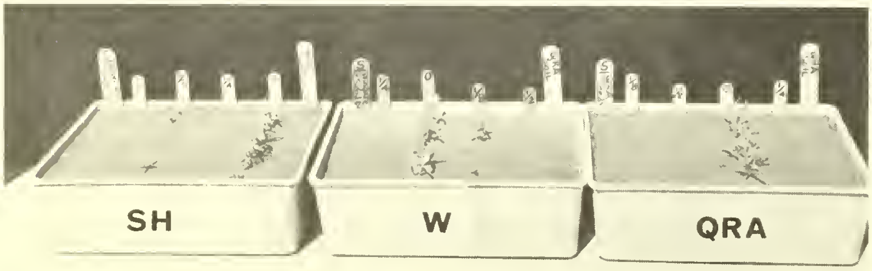
Moisture was maintained between saturation and field capacity during the first month of the experiment. Whenever the surface of the soil showed signs of drying the trays were subirrigated until the surface became moist, then excess water was allowed to drain through holes in the bottom of the trays. The trays were carefully rewatered as necessary during the first 2 weeks, when seedlings were emerging. Moisture was not as carefully controlled during the second 2 weeks, but it is unlikely the soils dried much below field capacity for more than a day or two.

The experiment was begun July 3, 1968. Emerging seedlings were counted until August 3, 1968, after which no new seedlings emerged. Seedlings were considered emerged when the cotyledons were 1/2 inch above the soil surface. Seedling emergence percentages were transformed to arc sin for analysis of variance.

Air and soil temperatures were determined by thermistors (Swanson 1967). Thermistors were placed at each depth of planting in each soil. No differences were found between soils or depths. During the first week when most seedlings emerged, daily air temperatures ranged from 58° to 82° F; corresponding soil temperatures varied from 54° to 71° F.

Figure 1.--Seedling establishment 30 days after seeding:

Wingate seeds in three soils.



Three seed sources in QRA soil.

Results and Discussion

Seedling emergence from planted seeds or fruits as highest on the surface of the soil, and ecreased with planting depth to none at 1/2 inch able 2). The three sources of seed gave essenally the same results.

For all sources of seeds and soils twice as many eedlings emerged from seeds as from fruits. The dvantages of seeds over fruits was greatest for urface planting (fig. 2). When planted 1/8 inch eep, fruits and seeds produced about the same umber of seedlings.

Seedling emergence for seeds planted on the urface reached a maximum 8 days after planting ig. 2). Seedlings began emerging the third day fter seeds were planted. Emergence was slower for surface-planted fruits, and for fruits and seeds planted 1/8 inch deep.

Some seedlings died regardless of the source of seed or soil. Seedling losses were somewhat greater in the Silver Hill loamy sand soil, however, presumably due to the poor moisture-holding capacity of this soil. Mortality was especially noticeable from the 12th to 14th day, when there were strong dry winds that probably imposed exceptional stresses on the young seedlings. Appearance of the dead and dying seedlings indicated mortality was caused by these stresses rather than by disease organisms, although some seedlings may have succumbed to damping-off fungi. Seedling survival 30 days after planting showed the same relationships as emergence: more seedlings survived from seeds planted on the surface.

able 2.--Number of winterfat seedlings per 100 seeds that emerged[1] or survived[2] from fruits or seeds planted at three depths--surface, 1/8 inch, and 1/4 inch

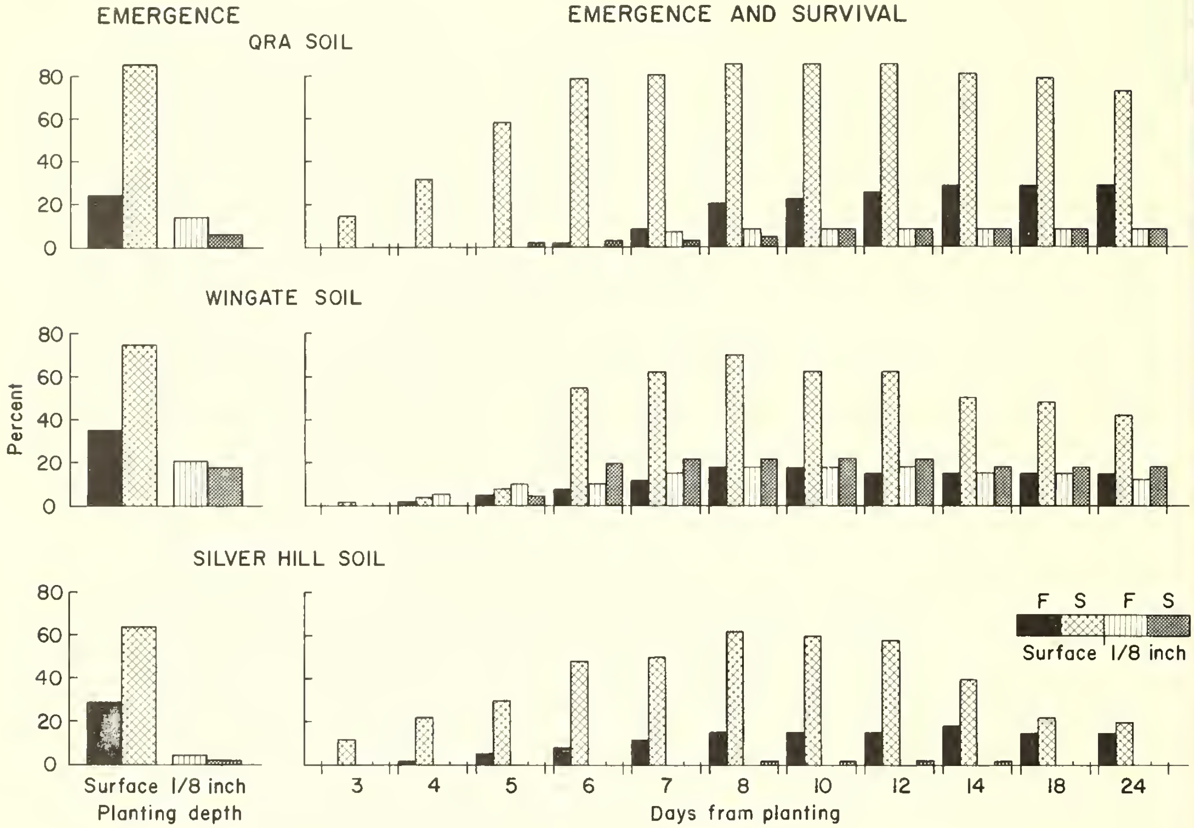
Source of seed	Source of soil	Fruit or seed planted	Seedlings per 100 seeds by planting depth					
			Surface		1/8 inch		1/4 inch	
			Emerged	Survived	Emerged	Survived	Emerged	Survived
			- - - - - - - - Number - - - - - - - -					
RA	QRA	F	28	28	8	8	0	0
		S	85	68	8	8	0	0
	Wingate	F	42	15	20	12	0	0
		S	80	35	8	5	0	0
	Silver Hill	F	20	8	2	2	2	2
		S	72	22	0	0	0	0
INGATE	QRA	F	18	12	15	15	0	0
		S	90	65	10	10	0	0
	Wingate	F	18	12	18	10	0	0
		S	70	42	22	18	8	2
	Silver Hill	F	50	42	10	8	0	0
		S	58	40	5	0	0	0
ILVER HILL	QRA	F	28	15	20	15	0	0
		S	80	55	2	2	0	0
	Wingate	F	48	30	28	20	2	0
		S	75	48	25	15	2	0
	Silver Hill	F	18	15	0	0	0	0
		S	62	20	2	0	0	0

Maximum number.
Number alive 30 days after seeding.

Figure 2.--Percentages of winterfat seedlings that emerged and survived from fruits (F) and seeds (S) planted on the surface and 1/8 inch deep:

Averages for three seed sources in each soil.

QRA seeds in QRA soil;
Wingate seeds in Wingate soil;
Silver Hill seeds in Silver Hill soil.



Conclusions

The results of this experiment suggest that shallow seeding of winterfat is essential. Relatively poor stands resulting from the 1/8-inch depth compared with surface planting indicate the optimum depth may be about 1/16 inch, although this depth was not tested. Threshed seeds appear to have advantages over whole fruits, not only because of the better stands produced, but also because seeds are less subject to wind movement and are more easily covered with a thin layer of soil. The fluffy nature of whole fruits also makes them difficult to handle and sow, especially with mechanized equipment.

Additional research with threshed seeds is needed to determine how soil moisture affects seedling emergence and survival from surface and shallow planting.

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U.S.D.A. FOREST SERVICE
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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Shading and Other Factors Affect Survival of Planted Engelmann Spruce Seedlings in Central Rocky Mountains

Frank Ronco[1]

Engelmann spruce seedlings survived best when healthy, vigorous stock was shaded in the field, but shading in nursery or hardening beds before outplanting did not increase field survival. Stock from the nursery and hardening beds survived equally well if healthy seedlings were planted. After field planting, light injury (solarization) caused most mortality; gopher and frost losses were high some years. Recommendations are made to help increase plantation success. (KEY WORDS: Engelmann spruce, Picea engelmannii, solarization, plant hardiness, nursery stock (forestry), forest regeneration (artificial), tree injuries)

Regeneration studies of Engelmann spruce (Picea engelmannii Parry), started in 1957,[2] indicated that seedlings were sensitive to intense sunlight at high elevations where spruce grows. Shading field-planted seedlings significantly increased survival. Observations of other plantations suggested that survival might have been increased if seedlings ad been shaded in the nursery or hardening bed[3] efore outplanting.

This Note summarizes the results of planting rials, made in 1960, 1961, and 1962, that tested hether preplanting shade affected survival.

Methods

Study Location and Treatment

The planting site is at 10,500 feet elevation on the White River Plateau in western Colorado. Three-year-old seedlings were planted in each trial. Seed source was the White River National Forest at elevations similar to the planting site.

Seedlings were grown for 2 years at an elevation of 7,000 feet in the Monument Nursery near Colorado Springs. One year before field planting, seedlings were lifted and transplanted either in the nursery or to a hardening bed near the planting site.

Seedlings in the nursery, hardening bed, and field were either unshaded (open grown) or partially shaded so that 12 treatments were available when all combinations of shade and location were utilized (table 1). Only a portion of the treatments was available in the 1960 and 1961 trials, but all were tested in the 1962 planting.

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[1] *Silviculturist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[2] *Ronco, Frank. Planting in beetle-killed spruce stands. U. S. Dep. Agr., Forest Serv., Rocky Mt. Forest and Range Exp. Sta. Res. Note 60, 6 p., illus. 1961. (Ft. Collins, Colo.)*

[3] *Stock lifted from the Monument Nursery was grown for 1 year in hardening beds near the planting site.*

Table 1.--Effects of partial shade and no shade in nursery, hardening beds, and field on 5-year survival of Engelmann spruce seedlings, field planted in 1960, 1961, and 1962

Shading treatment in--			Field planted in--			5-year survival		
Nursery	Hardening bed	Field	1960	1961	1962	1960 trial	1961 trial	1962 trial
						- - Percent - -		
Open	Shaded	Shaded	X	X	X	40	42	37
		Open	X	X	X	17	13	14
Open	Open	Shaded	X	X	X	43	53	30
		Open	X	X	X	22	18	10
Open--(Direct)--		Shaded	X	X	X	32	14	2
		Open	X	X	X	18	5	0
Shaded[1]--(Direct)--		Shaded		X	X		18	13
		Open		X	X		2	3
Shaded	Shaded	Shaded			X			41
		Open			X			7
Shaded	Open	Shaded			X			26
		Open			X			11

[1] Shaded only during third year in nursery in the 1961 trial.

In the nursery and hardening bed, horizontal screens of wood lath provided about 50-percent shade. Planted seedlings were shaded with wooden shingles, 6 to 8 inches wide, set in the ground so that seedlings were fully shaded 4 or 5 hours during midday. Each fall, shingles were removed to prevent snow crushing them against the seedlings.

Experimental Design

In each trial, 10 seedlings from each treatment were planted in rows 2 feet apart in each of 10 blocks; rows within blocks were randomized.

All trials were factorial experiments: 3 x 2, 1960; 4 x 2, 1961; and 2 x 3 x 2, 1962. The 1960 trial tested the effect of shade and no shade in the field on seedlings that were shaded in the hardening bed, open-grown in the hardening bed, and open-grown in the nursery (direct planted). The same classes of seedlings, in addition to shaded seedlings direct from the nursery, were compared in the 1961 trial. The 1962 trial tested the ffect of the two shading treatments on stock in the nursery, hardening bed and field. Survival fferences between treatments after the first wnter, second summer, and fifth summer were tested by analysis of variance.

Results

Effect of Shade

Regardless of preplanting treatment, field ading significantly increased survival of all seecngs (fig. 1). In contrast, field survival was not beneted by shading in the nursery or hardening bed, eept when stock direct from the nursery was plcted in the 1962 trial. That difference, however, was probably due to quality of stock and not to a cect shading effect; shaded seedlings in the nursery—protected by lath and sideboards—suffered less inter injury than those in the open.

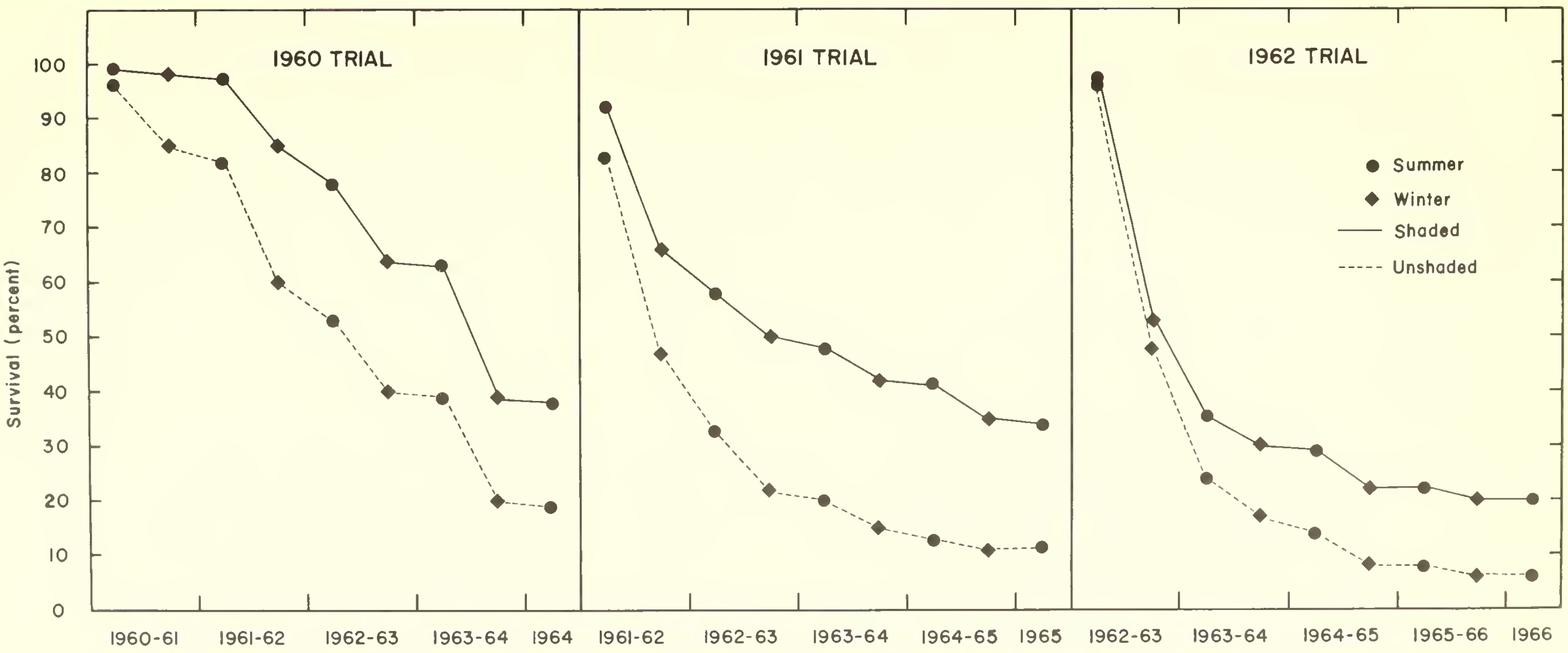

Figure 1.--Comparative survival of shaded and unshaded Engelmann spruce seedlings field planted in 1960, 1961, and 1962. (Percentages include all seedlings regardless of shade treatment in the nursery and hardening bed, and whether planted from the hardening bed or direct from the nursery.)

Quality of Stock

Throughout the study period, the vigor of planting stock influenced field survival more than preplanting shade. The 5-year survival of stock direct from nursery to field was better in the 1960 trial than in the 1961 or 1962 trials, probably because healthy stock was planted (table 1). In the 1961 trial, low survival was due to poor stock damaged either in cold storage at the nursery or in snowbanks at the planting site where seedlings were held temporarily before field planting. Poor survival in the 1962 trial was also attributed to unhealthy stock that had been damaged by drying winds and blowing soil particles during the winter before lifting.

After 5 years, hardening bed stock survived significantly better in the 1961 and 1962 trials than stock planted direct from the nursery (table 1). The advantage of hardening-bed over nursery stock, however, was more apparent than real. The differences in survival, which were evident throughout the study period, were attributed to the poor vigor of direct-planted stock rather than to any inherent characteristic of the hardening bed.

Survival Trend

The trend in seedling survival through the first 5 years was similar for all treatments and all trials (fig. 1). Survival the first summer exceeded 90 percent, except in the 1961 trial for direct-from-nursery treatments which averaged 72 percent.

Generally, more seedlings died overwinter than in summer, especially the first winter after planting in the 1961 and 1962 trials. In those trials, the sharp decrease in survival of unshaded and shaded seedlings in the field after the first winter was largely attributed to environmental factors. Furthermore, these losses were increased when poor quality stock was planted direct from the nursery.

Mortality was also relatively high during the second summer, but factors responsible for losses did not appear to be entirely associated with summertime conditions. Most mortality the second summer was due to seedlings that survived the winter in poor vigor and subsequently died. Thus, mortality was reported during the summer, but the causal factors were most likely associated with conditions of previous seasons. After the second summer, survival decreased gradually except for periodic heavy mortality caused by the mountain pocket gopher (Thomomys talpoides Richardson).

Causes of Mortality

Several environmental factors contributed to the mortality of planted seedlings.

Solarization.—Intense light at elevations where spruce grows inhibits photosynthesis, destroys chlorophyll, and may cause death of seedlings after prolonged exposure (table 2). This phenomenon, called solarization, was considered to be the primary cause of mortality in all trials, particularly during the firs winter and second summer following planting.[4]

Most seedlings exposed to intense sunlight after planting did not die immediately; they survived the first growing season even though they exhibited chlorotic foliage indicative of solarization. Irreversible injury was apparently incurred, however, since many seedlings died during the following winter when they were snow covered and received no direct sunlight.

Mountain pocket gophers.—Gophers killed many seedlings, especially in the 1960 trial (table 2). Gophers were more active during winter months, but they also killed some seedlings in all trials during most summers. In some instances, gophers caused nearly as much loss as solarization.

Other causes.—Losses from snow mold, frost heave, browsing, and trampling were generally low (table 2), although snow mold occasionally caused considerable mortality.

Summer frost.—Severe frost damage to foliage may also contribute to mortality. Seedlings planted in 1962 were heavily damaged by frost during the first growing season; few new shoots remained alive on open-grown seedlings, and some current growth was killed on about two-thirds of the shaded seedlings. Although most seedlings in all treatments survived the 1962 growing season, loss of new foliage reduced seedling vigor, and many trees subsequently died the first winter (fig. 1). At the end of 5 years, survival from the 1962 trial was noticeably lower than from previous plantings because of frost injury (table 1). Although frost injured some seedlings in other summers, it caused little mortality.

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[4] *Ronco, Frank. The influence of high ligh intensity on the survival of planted Engelmann spruce. D. F. dissertation, Duke Univ., Durham, N. C. 128 p. 1967. (Diss. Abstr. 29: 429B-430B, 1968.)*

Table 2.--Percent of total mortality caused by solarization, gopher damage, and other causes[1] in Engelmann spruce plantations, from seedlings planted in 1960, 1961, and 1962

Season following planting	Solarization						Gophers						Other causes[1]					
	Unshaded field			Shaded field			Unshaded field			Shaded field			Unshaded field			Shaded field		
	1960	1961	1962	1960	1961	1962	1960	1961	1962	1960	1961	1962	1960	1961	1962	1960	1961	1962
	- - - - - - - - - - - - - - - - Percent mortality - - - - - - - - - - - - - - - -																	
Summer 1960	4	--	--	[2]T	--	--	0	--	--	0	--	--	0	--	--	0	--	--
Winter 1960-61	14	--	--	3	--	--	0	--	--	0	--	--	0	--	--	0	--	--
Summer 1961	4	17	--	1	11	--	T	1	--	T	T	--	0	T	--	0	T	--
Winter 1961-62	18	35	--	7	37	--	3	1	--	8	3	--	6	5	--	5	1	--
Summer 1962	6	16	4	7	12	4	T	0	T	1	0	T	3	T	T	4	T	0
Winter 1962-63	9	9	47	9	10	49	5	T	1	8	2	1	2	T	2	4	0	5
Summer 1963	1	2	25	2	2	23	0	0	0	0	0	T	T	T	T	0	0	0
Winter 1963-64	2	4	7	3	3	4	20	1	T	35	6	1	T	T	T	0	0	T
Summer 1964	T	3	3	0	1	T	1	0	T	2	0	T	0	0	T	0	0	0
Winter 1964-65	--	2	3	--	3	3	--	0	3	--	7	6	--	T	T	--	0	0
Summer 1965	--	0	T	--	1	0	--	0	0	--	0	0	--	0	0	--	0	0
Winter 1965-66	--	--	T	--	--	1	--	--	T	--	--	T	--	--	0	--	--	0
Summer 1966	--	--	T	--	--	T	--	--	0	--	--	T	--	--	0	--	--	0
Total, 5 years[3]	58	88	91	33	80	85	30	4	6	54	18	10	12	8	3	13	2	5

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[1] Includes snow mold, frost heave, browsing, and trampling.
[2] T = Trace (less than 1 percent).
[3] Includes values of trace.

Expected Survival

Several treatments from each trial were grouped together to illustrate survival that might be expected when vigorous stock is properly planted and shaded in the field, and no action is taken to reduce gopher and frost losses (table 3). Survival in each trial decreased steadily during successive seasons following planting, primarily from light injury and gopher activity. At the end of 5 years, however, survival of shaded seedlings was still two to three times higher than that of unshaded seedlings in the field.

Table 3.--Estimated expected survival in spruce plantations. (Percentages are averages for trials where hardening-bed stock was field shaded.)

Seasons after planting	Survival from-- 1960 trials	1961 trials	1962 trials
	- - -	Percent	- - -
First:			
Summer	99	99	95
Winter	98	85	62
Second:			
Summer	97	75	52
Winter	[1]86	68	[1]47
Third:			
Summer	77	66	46
Winter	[1]64	[2]58	[2]36
Fourth:			
Summer	62	56	36
Winter	[3]43	[2]48	[1]34
Fifth:			
Summer	42	47	33

Between summer and following winter, gophers caused the following percent of decrease in survival:

[1]26-50 percent
[2]51-75 percent
[3]76-100 percent

Discussion and Conclusions

Shade appreciably increased field survival only when applied to seedlings in the field, but its effectiveness was reduced when stock of poor vigor was planted. Although the trials were not designed to test the effect of stock quality on survival, the results suggested that healthy stock—providing it was shaded in the field—survived well whether planted direct from the nursery or from the hardening bed.

Poor-quality stock was especially susceptible to the harsh environment associated with most spruce planting sites. For example, while nearly all healthy and winter-injured stock planted direct from the nursery in 1962 survived the first growing season, exposure to summer frosts and high light intensities after planting caused nearly twice as many of the unhealthy seedlings to die overwinter.

The loss of new foliage from frost was so severe the first summer in the 1962 trial that even healthy stock survived poorly over the first winter. Fros injury can be reduced in most instances, however by planting seedlings under natural shade.[5]

The generally better survival of hardening-bed over nursery stock was related more to seedling vigor than any physiological conditioning due to the beds. The equally good survival of stock from the nursery and hardening bed in the 1960 trial supports that conclusion, and suggests that the hardening bed is an unnecessary step in planting operations. The better quality of stock from the hardening bed was attributed to several controllable factors: (1) stock lifted 1 or 2 days before planting was not exposed to storage conditions tha enhance the development of mold; (2) stock wa culled more rigorously because of frequent handling; (3) needles of seedlings were not injured by blowing soil particles or drying winds—injuries tha are apt to occur in low-elevation nurseries during open winters.

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[5] *Ronco, Frank. Lessons from artificia regeneration studies in a cutover beetle-kille spruce stand in western Colorado. U. S. Fores Serv. Res. Note RM-90, 8 p., illus. 1967 (Rocky Mt. Forest and Range Exp. Sta., Ft Collins, Colo.)*

Shaded seedlings that survived the second summer appeared to be less susceptible to solarization afterward. Although mortality occurred throughout the study period, fewer trees died after the first year. The majority of deaths after the first year, however, still were attributed to solarization except for periods of intense gopher activity. Losses from solarization could be reduced if shade was continuous during the day and growing season. Seedlings in these trials were shaded by shingles during midday, but were exposed to full sunlight during early morning and late afternoon. Light intensity at those times will still reach 13,000 foot-candles on a clear day.[6] Seedlings were also fully exposed each spring and fall during the period when the shingles were not in place.

Expected survival connot be precisely predicted for spruce plantations, because the impact of numerous environmental factors varies from year to year. Results summarized in table 3 indicate, however, that about half of the seedlings in some plantations will survive for five growing seasons, even without gopher control, if healthy stock is planted and seedlings are shaded in the field. Survival could probably be maintained near the second-growing-season level if gophers were controlled, although some loss from frost, snow mold, and other injuries could be expected.

Recommendations

Based on the results of the planting trials, and on the assumption that seedlings are stored, transported, and planted properly, the following recommendations are suggested to increase survival in spruce plantations:

1. Use stock direct from the nursery that has been protected from drying winds and blowing soil particles.
2. Use only healthy planting stock; discard seedlings of doubtful vigor.
3. Provide adequate and permanent protection in the field by planting seedlings under the crowns of live trees or on the north side of stumps, logs, and logging slash large enough to fully shade the seedlings for several years.
4. To compensate for unavoidable losses, plant two to three times as many seedlings per acre as the number considered adequate for stocking 5 years after planting.
5. Maintain an adequate gopher-control program.

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[6] *Spomer, G. E. Physiological ecology of alpine plants. Ph.D. dissertation, Colo. State Univ., Ft. Collins. 1962. (Diss. Abstr. 23: 3094-3095, 1963.)*

U S D A FOREST SERVICE
RESEARCH NOTE RM-164

REST SERVICE
. DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Preemergent Herbicides for Preparing Ponderosa Pine Planting Sites in the Southwest

L. J. Heidmann[1]

On an area with dense perennial grass cover, atrazine at 10 pounds per acre resulted in heaviest grass kill (68 percent) and highest tree survival. Tree survival generally was poor, however, partly due to heavy grass competition because herbicides could not be applied early enough, and partly because of animals. Herbicides did not damage pine seedlings. (KEY WORDS: Herbicides, Pinus ponderosa, Festuca arizonica, Muhlenbergia montana, tree planting)

One of the problems in planting ponderosa ne (*Pinus ponderosa* Laws.) in the Southwest is mpeting vegetation, primarily perennial grasses. rasses such as Arizona fescue (*Festuca arizonica* asey), which grow during the spring dry period May and June, are capable of using most of the ailable soil moisture at the expense of newly anted pine seedlings. The cheapest and most fective method of eliminating grass is to kill it th herbicides.[2] In Arizona, we have found that il moisture is significantly higher on plots with a ad grass mulch than on plots from which the grass s been entirely removed.[3] The differences are nificant to a depth of 20 inches.

Several systemic herbicides have successfully led perennial grasses in the Southwest. Dalapon, wever, has proved to be the cheapest and most fective. A rate of 5 pounds (active ingredient) the sodium salt of dalapon per acre usually results in a grass kill of 90 percent or more. Treated areas have remained relatively grass-free for 2 or 3 years.

A disadvantage of systemic herbicides is that they must be applied while the grass is actively growing. This means the herbicide must be applied the season before tree planting in a separate operation. The ideal situation would be to use an herbicide that could be applied at the same time the trees are planted. In Iowa, White[4] applied simazine to the soil from a sprayer mounted on a tree planter at the same time several species of conifers and hardwoods were planted. White did not mention unsprayed controls, but first-year survival on the sprayed areas was 89 percent compared to 60 to 75 percent for previous plantings. The herbicide was applied to ground that had already been prepared mechanically.

The Study

In 1965, a test of three preemergent herbicides was begun on two areas of the Fort Valley Experimental Forest near Flagstaff, Arizona. Area S-3, clearcut of sawtimber in 1963, had supported a mature stand of ponderosa pine that had averaged 11,000 board feet per acre. In 1965, there was

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[1] *Associate Silviculturist, located at agstaff, in cooperation with Northern Arizona iversity; central headquarters are maintained Fort Collins, in cooperation with Colorado ate University.*

[2] *Heidmann, L. J. Herbicides for preparing nderosa pine planting sites in the Southwest. S. Forest Serv. Res. Note RM-83, 4 p., illus. 67. (Rocky Mt. Forest and Range Exp. Sta., rt Collins, Colo.)*

[3] *Heidmann, L. J. Use of herbicides for anting site preparations in the Southwest. Forest. 67: 506-509, illus. 1969.*

[4] *White, Gordon. Chemical weed control as a planting operation. J. Forest. 60: 256-257. 1962.*

almost no vegetation on the ground. The other area, Wing Mountain, supported a dense stand of perennial grasses, mainly Arizona fescue and mountain muhly (Muhlenbergia montana (Nutt.) Hitchc.) (fig. 1). Around the plots were scattered groups of saplings and small poles, with occasional sawtimber-size trees remaining from logging operations in the 1920's.

The study was a randomized block design with four replications. Each block consisted of two rows of five plots. In each plot five rows of five ponderosa pine seedlings were planted at a spacing of 3 by 3 feet. The trees were planted by hand, with the aid of planting bars. The 2-0 stock planted at S-3 was raised in the U.S. Forest Service Nursery at Placerville, California, from seed collected on the Kaibab National Forest near the Fort Valley Experimental Forest. At Wing Mountain, 3-0 stock raised in a small experimental nursery at Fort Valley was used. Tree planting was not completed until the end of May because of an exceptionally wet spring.

After planting, each of the 10 plots in a block was randomly assigned one of the treatments listed in tables 1 and 2.[5] Each herbicide was mixed with sufficient water plus a wetting agent[6] to obtain complete coverage of the vegetation, then applied with a 3-gallon, garden-type pressure sprayer. No effort was made to protect the trees from the spray solution.

Tree survival was checked every 2 weeks until the summer rains began in July, then monthly until October 1. In 1966 and 1967 survival was checked three times during the growing season. When the last survival check was made in October of each year, the total height of each tree was measured to the nearest 0.1 inch.

Near the end of the first summer the grass kill at Wing Mountain was estimated to the nearest 5 percent. At S-3 no estimates were made since little ground cover was present.

Results

S-3 plot—
2-year-old clearcut, little ground cover

Mean seedling survival at S-3, at the end of the first year, was 88 percent (table 1).[7] Survival was higher on the herbicide-treated plots than on the unsprayed control. Although the differences between treated plots and the control averaged 15 percent, they were not statistically significant. Survival the following spring was considerably lower. One of the main causes of mortality was damage by animals (table 1).

Animals destroyed about 13 percent of the trees during the study, most of them the first winter. Primarily responsible were elk (Cervus canadensis), mule deer (Odocoileus hemionus), pocket gophers (Thomomys spp.), and rabbits and hares (Sylvilagus spp. and Lepus spp.). Another 13 percent of the trees did not visibly break dormancy in 1965 and were dead in the spring of 1966. Over 11 percen of the trees died of unknown causes and 8 percen from faulty planting, which included planting trees that were too small or of poor quality.

Total heights were not significantly differen among any of the treatments throughout the study (tables 1 and 2). Because of browsing, average height in some instances was less at the end o

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[5] *All herbicides were donated by the Geigy Chemical Company. Company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture.*

[6] *Wetting agent used was X-77, a nonionic spreader activator manufactured by Colloidal Products Corporation, Sausalito, California.*

[7] *Results are experimental, and are not t be taken as recommendations by the U.S. Department of Agriculture.*

Figure 1.--Wing Mountain study area on Fort Valley Experimental Forest, near Flagstaff, Arizona. Area supported a dense cover of grasses, primari Arizona fescue and mountain muhly.

Grass kill was best on that portion of the area sprayed with atrazine at a rate of 10 pounds per acre.

le 1.--S-3 plot (little ground cover): Percent survival, total height, and percent mortality in relation to number of ponderosa pine seedlings planted in 1965, by herbicidal treatment[1]

atment rate ./acre)	Survival			Total height			Cause of mortality, 1965-67						
	1965	1966	1967	1965	1966	1967	Animal damage	Faulty planting	Physiological	Drought	Miscellaneous	Unknown	Total
	- - Percent - -			- - Feet - -			- - - - - - - - - - Percent - - - - - - - - - -						
e(check)	75	61	46	0.38	0.33	0.39	10	15	14	1	1	12	53
azine:													
2.5	96	70	61	.32	.38	.49	16	3	8	0	3	9	39
5.0	92	66	42	.32	.34	.40	11	9	14	1	2	20	57
10.0	89	57	51	.33	.33	.35	9	4	21	2	2	11	49
pazine:													
2.5	89	66	60	.33	.38	.46	13	9	13	0	4	3	42
5.0	92	65	55	.36	.40	.49	21	4	6	2	2	10	45
10.0	91	58	45	.31	.29	.37	5	7	24	1	1	17	55
azine:													
2.5	87	62	54	.32	.33	.41	10	11	11	3	2	8	45
5.0	89	45	37	.35	.38	.46	20	4	19	0	6	14	63
10.0	84	62	49	.35	.32	.38	16	15	4	1	3	11	50
Mean	88	61	50	.34	.35	.42	13.1	8.1	13.4	1.1	2.6	11.5	49.8

nazine = 2-chloro-4,6-bis-(ethylamino)-*s*-triazine.
opazine = 2-chloro-4,6-bis(isopropylamino)-*s*-triazine.
razine = 2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine.

he second growing season than at the end of the irst. Approximately 44 percent of the trees were rowsed during the study, and slightly over 30 ercent of the trees that died had been browsed it one time or another.

Precipitation was unusually heavy in 1965. Over .5 inches fell in April as compared to 0.42 in April 966. Over 23 inches of precipitation fell from pril through November, which was twice as much is for the same period in 1966. Total precipitation n 1967 was similar to 1965, although the distribution differed.

Ving Mountain plot—
10-year-old-clearcut,
lense grass cover

First-year survival at Wing Mountain was only 0 percent (table 2). As at S-3, there were no ignificant differences among treatments in either urvival or total height. Drought caused almost ialf of the mortality. First-year survival was highest on plots treated with 10 pounds of atrazine er acre (fig. 1). These plots also had the highest rass kill. Approximately 11 percent of the mortality was caused by livestock, which entered through gap in the fence during the summer of 1966. bout 15 percent of the mortality occurred during he first and second winters. A situation similar o that at S-3 existed at Wing Mountain in that ver 10 percent of the trees never broke dormancy n 1965.

A rate of 10 pounds per acre of atrazine gave an average grass kill of 68 percent, which was significantly better than the other treatments. Propazine at 10 pounds was next best, with a 36 percent grass kill.

Discussion

The preemergent herbicides—simazine, atrazine, and propazine—appear to be safe for use with ponderosa pine seedlings at rates up to 10 pounds per acre.

At Wing Mountain, where heavy grass occupied the site, results were disappointing. The trees appeared to be in good condition for several weeks following planting, but then mortality became heavy. The onset of mortality coincided with the time when fescue was growing vigorously and precipitation was lacking. Despite the fact that the early spring was unusually wet, there was a period of 47 days after tree planting during which about 0.25 inch of rain fell. Grass kill was generally poor. This may be partially explained by the fact that the grass could not be sprayed until after growth had begun because of heavy snow in the spring. By the time it was possible to visit the study area for the first time in 1965, the grass was already growing. Preemergent herbicides are more efficient when the material can be incorporated into the soil during the dormant season.

Table 2.--Wing Mountain plot (dense grass cover): Percent survival, total height, and percent mortality in relatio to number of ponderosa pine seedlings planted in 1965, by herbicidal treatment[1]

Treatment and rate (Lb./acre)	Survival			Total height			Cause of mortality, 1965-67						
								Winter kill					
	1965	1966	1967	1965	1966	1967	Drought	First winter	Second winter	Physiological	Animal damage	Miscellaneous	Tota
	- - Percent - -			- - Feet - -			- - - - - - - - - - Percent - - - - - - - - - -						
None(check)	54	33	29	0.23	0.19	0.27	46	7	0	9	8	1	71
Simazine:													
2.5	36	15	11	.20	.24	.30	64	11	2	3	9	0	89
5.0	40	23	15	.24	.21	.32	60	2	6	6	9	2	85
10.0	53	28	24	.25	.20	.34	47	7	2	8	12	0	76
Propazine:													
2.5	47	19	10	.22	.17	.24	51	14	3	8	15	1	92
5.0	56	31	22	.25	.20	.28	44	5	11	10	6	2	78
10.0	59	31	20	.24	.16	.26	41	3	5	18	11	2	80
Atrazine:													
2.5	48	18	16	.20	.19	.26	51	17	2	10	10	1	91
5.0	57	26	23	.26	.17	.21	43	2	2	18	4	1	70
10.0	63	25	22	.24	.18	.32	37	19	0	12	8	2	78
Mean	51	25	19	.23	.19	.28	48.4	8.7	3.3	10.2	9.2	1.2	81.

[1] Simazine = 2-chloro-4,6-bis-(ethylamino)-s-triazine.
Propazine = 2-chloro-4,6-bis(isopropylamino)-s-triazine.
Atrazine = 2-chloro-4-ethylamino-6-isopropylamino-s-triazine.

The trees planted at Wing Mountain were lifted several weeks later than normal and were in a more advanced state of growth, which may have contributed to their mortality.

Survival of pine seedlings was highest the first year on plots with the heaviest grass kill. Differences in survival were not significant, however, even though differences in grass kill were. At the end of the study, survival was higher, but not significantly so, on control plots.

Mortality during the first and second winters at Wing Mountain may have been due to winterkill. Southwestern winters are often characterized by extended periods when there is no snow cover and the ground is frozen. At S-3 a few trees died during the winter but these were included under miscellaneous causes.

A high percentage of mortality at both areas was attributed to physiological causes. An appreciable number of trees remained green throughou the summer but showed no visible signs of growth

Many of the trees, especially at S-3, were kille by wildlife even though they were sprayed wit repellents every year and the area was fenced This was the first instance in which the author ha noted extensive activity by deer and elk insid small fenced plots.

Conclusions

1. Simazine, atrazine, and propazine at rates up t 10 pounds of active ingredient per acre wa applied to ponderosa pine seedlings withou damage to the trees.
2. Atrazine was an effective grass killer for use i the Southwest. Previous studies have show simazine to be effective also, but at a consider ably higher cost.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-165

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fourwing Saltbush Survival after Inundation[1]

Earl F. Aldon[2]

Four-week-old fourwing saltbush transplants are subject to high mortality if planted in areas likely to be inundated for longer than 30 hours.

(KEY WORDS: Atriplex canescens, fourwing saltbush, flood control, watershed management, soil-binding plants)

Chamiza or fourwing saltbush (Atriplex canescens (Pursh) Nutt.) is considered an excellent forage plant for domestic livestock. Its virtues for reseeding rangelands have been known for a long time.[3] Recently, this plant has been used in watershed restoration work on alluvial flood plains on the Rio Puerco drainage in New Mexico.[4] Fourwing saltbush is also being planted behind flood detention structures by the Bureau of Land Management to trap sediment above a dam's main pool, thereby prolonging the useful life of the structure. Establishment of plant cover behind these structures will also enhance wildlife values. If plantings are to be successful, however, they must be made where high water levels will not be maintained for long periods of time. This study was designed to find how long fourwing saltbush plants could withstand inundation and still survive.

Methods

Ten 4-week-old fourwing saltbush plants, each in a 3-inch plant band, were placed in each of 22 plastic buckets 13 inches deep. Soil was packed in the spaces between the bands. Tap water was poured into the buckets to the brim, thus covering the plants with about 10 inches of water. This water was "aged" several days and air pumped through it for 12 hours prior to its use to remove any chlorine. The filled buckets were placed outdoors where they would be subjected to diurnal temperature fluctuations.

A thermograph in a standard U.S. Weather Bureau shelter was maintained on the site to monitor air temperatures.

At 2-hour intervals from 10 a.m. through 4 p.m. for 3 days, the water was syphoned off one bucket and the bucket was brought into the greenhouse where 80° F. daytime and 65° F. nighttime temperatures were maintained. Survival dropped rapidly somewhere between the 30th and 48th hour of submergence. Since this occurred overnight on the first run, a similar test was made for 2-hour intervals between the 32nd and 48th hour. All conditions in this second run were similar to the first run, so the data were analyzed together.

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[1] *Study conducted in cooperation with the Bureau of Land Management, U. S. Department of the Interior, Albuquerque, New Mexico.*

[2] *Principal Hydrologist, located at Albuquerque, in cooperation with the University of New Mexico; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[3] *Springfield, H. W., and Housley, R. M., Jr. Chamiza for reseeding New Mexico rangelands. U.S. Dep. Agr., Forest Serv., Southwest. Forest and Range Exp. Sta. Res. Note 122, 5 p., illus. 1952. Tucson, Ariz. [Consolidated in 1953 with Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.]*

[4] *Aldon, Earl F. Fourwing saltbush can be field planted successfully. 1970. (In preparation for publication, Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Fort Collins, Colo.)*

Within 10 minutes after water was removed from the buckets, some plants were cut into sections and treated with 2,3,5-triphenyl-tetrazolium chloride (TTC).[5]

After 5 days in the greenhouse, the dead plants in each bucket were counted and percent mortality computed. A probit analysis of mortality percentages over time was made.[6] These data were then analyzed by regression with mortality as the dependent variable.

Air and water temperatures were measured at the time the plants were removed from the water, and the data were related by regression analyses.

Results

Four-week-old fourwing saltbush transplants tolerated 29 hours of submergence before 50 percent of the plants died. After 40 hours under water, almost 70 percent of the plants were dead.

The relationship between percent mortality and hours submerged was calculated by means of probit and logarithmic transformations, respectively[6] (fig. 1). The scatter of data points is in part due to small numbers of plants (10 per "dose").

Air and water temperatures were highly correlated, r = 0.98. Water temperatures ranged from a low of 54° F. to a high of 98° F. High water temperatures were maintained for only a few hours in the afternoons as determined from the air temperature data and were not lethal to the plants. These water temperatures are similar to those encountered under field conditions.

Plant tissue that was under water for any length of time did not stain red with TTC as detected visually. Plants were without oxygen soon after submergence, and the TTC test for viable tissue cannot be used under this condition. Many submerged plants did recover and continue to grow in the greenhouse, however.

When field planting fourwing saltbush transplants, locate plants where they will not be subjected to more than about 30 hours of flood water submergence. Longer periods under water will result in high mortality.

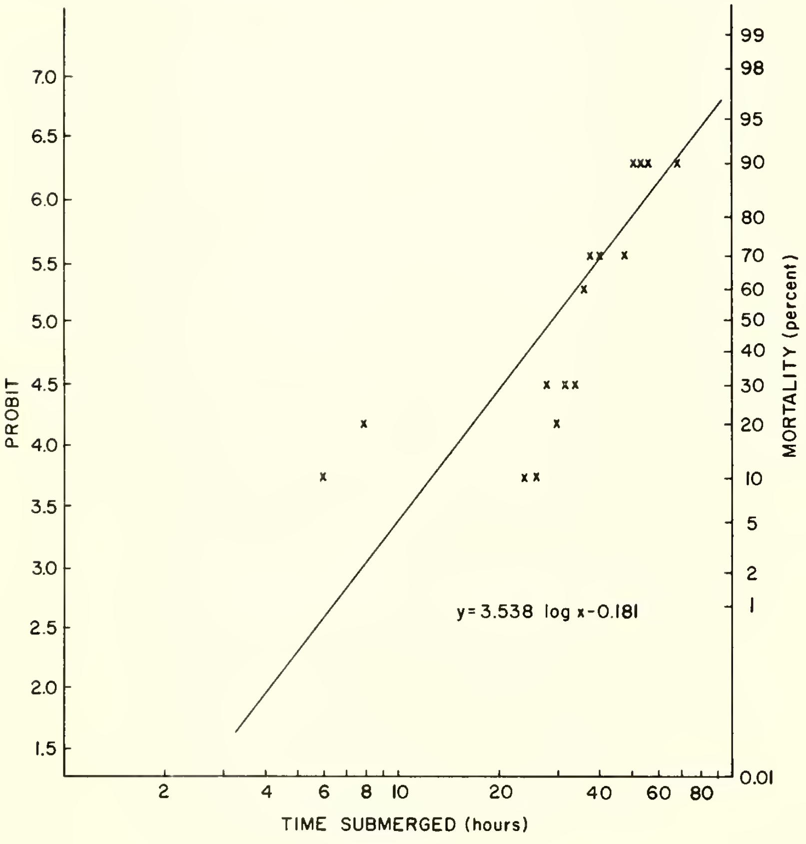

Figure 1.--Relationship between hours submerged and the percent mortality of young fourwing saltbush plants.

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[5] Parker, J. *Some applications and limitations of tetrazolium chloride. Science 118: 77-79. 1953.*

[6] Finney, D. J. *Statistical method in biological assay. Ed. 2, 668 p., illus. New York: Hafner Publ. Co. 1964.*

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U S D A FOREST SERVICE
RESEARCH NOTE RM-166

REST SERVICE
. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Growing Fourwing Saltbush Transplants for Field Planting[1]

Earl F. Aldon[2]

Seeds can be germinated in plant bands when air temperatures are around 65°F. Seedlings should be transplanted when soil moisture conditions are optimum. (KEY WORDS: Atriplex canescens, fourwing saltbush, flood control, watershed management, soil-binding plants, transplanting)

Fourwing saltbush or chamiza (Atriplex canescens (Pursh) Nutt.) is currently being planted for erosion control and as wildlife food and cover by the Bureau of Land Management on the Rio Puerco in New Mexico. For two consecutive years, field plantings have been made with 4- to 6-week-old transplants. Success of these field plantings is reported elsewhere.[3] Of several different methods tried for growing these transplants, the most successful one is reported in this Note.

Previous Work

Springfield[4] has shown that the optimum temperature for germinating fourwing saltbush is between 55° and 75° F; seeds began germinating within 3 days at 65° and 73° F. Germination of this seed is highest when moisture approximates field capacity, but moisture stress may be less important at optimum temperatures.[5]

Special storage conditions for fourwing saltbush seeds are not necessary.[6] Refrigeration did not improve the retention of seed viability. Viability was retained at a high level for 6 years when seeds were stored under dry conditions at temperatures of 55° to 95° F.[6]

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[1] *Research reported here was conducted in cooperation with the Bureau of Land Management, U. S. Department of the Interior, Albuquerque, New Mexico.*

[2] *Principal Hydrologist, located at Albuquerque, in cooperation with the University of New Mexico; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[3] *Aldon, Earl F. Fourwing saltbush can be field planted successfully. 1970. (In preparation for publication, Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Ft. Collins, Colo.)*

[4] *Springfield, H. W. Temperatures for germination of fourwing saltbush. J. Range Manage. 22: 49-50, illus. 1969.*

[5] *Springfield, H. W. Germination of fourwing saltbush seeds at different levels of moisture stress. Agron. J. 58: 149-150, illus. 1966.*

[6] *Springfield, H. W. Cold storage not required for fourwing saltbush seeds. J. Range Manage. 21: 335-336. 1968.*

Methods

1. Collect seeds from plants growing near the site where planting is contemplated (fig. 1). One large plastic garbage bag (30 gal. size) full will yield enough seeds for 2,000 transplants. Gather in late October or early November after seeds are mature and dry, but before they fall. Seeds are a light brown color at this time (all times used in this Note refer to conditions near Albuquerque, New Mexico).
2. Store in open plastic bags in a dry place over-winter at room temperature.
3. In early April, remove wings from seeds by rubbing between the palms of hands. The winged chaff is easily blown away. A wide-mesh screen can be used to collect the seeds and let the chaff drop through if hand rubbing leaves some of the wings attached.
4. Select 100 seeds at random and cut them in half (a nail clipper works well). Count the filled and hollow seeds. The filled seeds usually are viable (capable of germinating).
5. Compute the number of seeds needed to insure one plant in each plant band as follows:

   100 seeds cut open
   70 were empty
   30 were filled

   $$\frac{30}{100} = 0.3 \text{ viable seed}$$

   In this instance, if 15 seeds are planted, probably 4 will germinate.
6. Use 2-inch by 2-inch wide and 3-inch de heavy-weight felt paper plant bands (fig. Place bands in old fruit or vegetable crates for support. Crates that hold about 42 plant bands are easily handled. These crates should have chicken wire on the bottom for added strength and a thick plastic sheet over the wire. The plastic sheet keeps taproots from penetrating the soil surface if bands are in contact with the ground. The plastic sheet is important, for when the taproot hits this impermeable layer it will turn. When this happens, top growth seems to be stimulated.
7. Mix thoroughly 2/3 good garden soil with 1/3 soil taken from under a fourwing saltbush plant. This extra mix is necessary to inoculate the plant with growth-stimulating microorganisms. The specific organism has not been isolated as yet, but plants grown in this mix do better than those grown in garden soil only.
8. Put soil to within 1/2 inch from the top of the plant bands. Tamp in place. No special material such as gravel is needed at the bottom of the bands.
9. Place enough seeds on the surface to produce about four seedlings and cover with 1/4 inch of the soil mix. Planting should start sometime between mid-April and mid-May when outdoor temperatures are optimum (65° F.).
10. Water four times daily, or as needed, with a fine mist to keep the surface moist. Heavy watering will float seeds out of soil. Keep the bands in a location where the sun will

Figure 1.--A mature plant with ripe seeds. Seeds should be golden yellow before they are collected.

Figure 2.--Four- to six-week-old seedlings growing in plant bands.

them for several hours a day. When plants are up 1/2 inch they can be flooded from the top when needed.

11. When plants are about 3 weeks old, thin to one per band.
12. Remove grasses and weeds from the bands as they appear.

Field Planting

1. Plant in areas that will be flooded periodically but will not be inundated for longer than 30 hours.[7]
2. Plant in late July or early August after the area has received some moisture. The soil should not be too dry.
3. Seedlings should be planted before 10:00 a.m. to keep stresses on plants to a minimum.
4. Keep plants shaded or covered and well watered while transporting to the planting site and while at the site.
5. Use a post-hole digger to make a 4-inch-deep hole for planting.
6. Insert plant band and tamp soil around it. Roots apparently do not need to be laid straight down. They can be bent around but should not be broken.
7. Plant at 5-foot spacing. In favorable years, plants can grow 2 feet tall in the first year.
8. Cover transplanted seedlings with straw to minimize stresses.
9. Spray straw mulch and fourwing saltbush plants with a 1:1 mixture of water and animal repellent.

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[7] *Aldon, Earl F. Fourwing saltbush survival after inundation. USDA Forest Serv. Res. Note RM-165, 3 p., illus. 1970. (Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.)*

Agriculture --- CSU, Ft. Collins

U S D A FOREST SERVICE
RESEARCH NOTE RM-167

REST SERVICE
S DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Lindane Spray Effective Against Mountain Pine Beetle in the Rocky Mountains

Robert E. Stevens and James C. Mitchell[1]

Lindane-diesel oil solution killed mountain pine beetle (Dendroctonus ponderosae Hopk.) in ponderosa pines (Pinus ponderosa Laws.) just as effectively as the commonly used insecticide, ethylene dibromide, but takes only 10 percent as much total spray.

(KEY WORDS: Insecticides, lindane, insect control, Scolytidae, Dendroctonus ponderosae, Pinus ponderosa)

Lindane[2] insecticide is used throughout much of the United States for control of bark beetles. Sprayed on the bark of individual infested trees, it is highly effective in killing the beetles in place or as they emerge. Lindane is registered for control of the mountain pine beetle, Dendroctonus ponderosae Hopkins, but it has never been commonly used in the Rocky Mountain area.

Lindane is often preferable to ethylene dibromide (EDB), the insecticide generally used, and is equally as effective. Lindane has the advantage that less than 10 percent as much total spray is needed, which greatly reduces transportation costs, and can result in cheaper and more efficient control operations. We tested lindane in the summer of 1969 to evaluate its effectiveness here against mountain pine beetles in ponderosa pine, Pinus ponderosa Laws.

Methods

Twelve infested ponderosa pines were selected in spring 1969 on the Roosevelt National Forest, about 35 miles northwest of Fort Collins, Colorado. Diameter of the trees averaged 10.4 inches at breast height (range 8-11) and the trees were infested to an average height of 15.9 feet (range 9-25).

The trees were felled in mid-June, and the most heavily infested portion of each tree was cut into three equal sections. One of three treatments was assigned to each section—1.5 percent lindane spray, 0.5 percent spray, or unsprayed check. The treatments were arranged so that each tree received all three treatments, and each treatment was applied an equal number of times in each section—top, middle, and bottom.

The test bolts were sprayed in the field on July 1, 1969. At this time the beetles were in the larval, pupal, and callow adult stages. The spray, prepared from a 20 percent lindane concentrate and diesel oil, was applied with a common garden sprayer until the bark was thoroughly wet but not dripping.

The sprayed logs were left in shaded locations in the field until July 30, when 16-inch bolts were

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[1] *Principal Entomologist and Forestry Research Technician, respectively, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[2] *1,2,3,4,5,6 - hexachlorocyclohexane, 99 percent or more gamma isomer.*

cut from the center of each log and caged individually in a partially shaded location in Fort Collins. The cylindrical screen cages (Germain and Wygant 1967) permitted relatively unrestricted air movement around the bolt, and effectively separated the beetles from the bolt soon after emergence.

Beetles were collected daily, placed individually into gelatin capsules in plastic petri dishes with a wad of moistened paper toweling, and held for 3 days. We recorded numbers of beetles emerging and numbers alive and dead at the end of the holding period. Emergence had just started at the time of caging, and continued through September 10, when collections terminated. A few beetles were still being collected daily at that time.

On July 7, to get information on amounts of insecticide needed under operational conditions, we felled and sprayed 33 infested trees in Rist Canyon, about 10 miles west of Fort Collins. These trees averaged 10.6 inches d.b.h. (range 6-16) and were infested to an average height of 19.8 feet (range 8-27). About 7-3/4 gallons of mixed spray were required to treat the 33 trees; this amounts to about 1 quart of spray per tree, contrasted with the 4 to 5 gallons of EDB spray needed to treat an average tree.

Results and Discussion

Both lindane concentrations effectively reduced numbers of emerging beetles, and killed many beetles that were able to emerge (table 1). Although emergence and survival were somewhat lower with the higher insecticide concentration, the 0.5 percen solution is sufficiently toxic. However a slightl stronger formulation is commonly used.

Lindane and EDB kill beetles in different ways Lindane is a long-lasting, residual-contact insecticide, while EDB is a fumigant. EDB only kill beetles under the bark as the material vaporize beetles that are able to emerge are presumed to b healthy. Characteristically, lindane causes mos mortality under the bark (Lyon 1965), but it als fatally poisons most of the few beetles that are abl to emerge and fly off. Thus the presence of som emergence holes on lindane-treated logs does no mean the treatment was unsuccessful. Subletha effects are probably such that only a portion of th surviving beetles can successfully attack green trees Therefore the results in table 1 probably underestimate the effectiveness of the treatments.

Recent work on the West Coast (Lyon and Swai 1968) has shown that spraying lindane any tim of the year is effective against the western pin beetle, *D. brevicomis* Lec. This should also hol true against the mountain pine beetle in the centra Rocky Mountains. Lindane spray should also b equally effective here against mountain pine beetle in lodgepole pine, and against western pine beetles

Our test demonstrated that lindane will kill th mountain pine beetle in ponderosa pine in th Rocky Mountain area. While experience is neede to develop reliable cost figures, lindane should b considerably cheaper to use than EDB on felle trees, or falling and burning. Falling infested tree is necessary to fully capitalize on lindane's lo volume advantage; spraying standing trees require a considerably greater volume of material. Spray

Table 1.--Effect of lindane-diesel oil sprays on mountain pine beetles in ponderosa pine, Colorado, 1969

Treatment	Bark area	Number of beetles that-- Emerged		Number of beetles that-- Survived[1]		Reduction due to treatment[2]
	Sq. ft.	Total	Per sq. ft.	Total	Per sq. ft.	Percent
Sprayed:						
1.5 percent	38.9	96	2.5	15	0.4	97
0.5 percent	38.2	137	3.6	48	1.3	92
Unsprayed (check)	37.6	815	21.7	618	16.4	--

[1] Following 3-day holding period.

[2] Corrected (formula by Abbott 1925) to account for natural mortality.

g down logs also ''bounces'' less material off the
rk, minimizing environmental contamination. Buck-
g and limbing are necessary only to the extent
at they make it easier to spray all of the infested
rtion of the bole.

It is important to note that these results concern
ly the effectiveness of the insecticide in killing
etles. They do not deal with the larger question
controlling an infestation. The treating method
elf—using an insecticide, burning, or salvage log-
ng, for example—is only part of the control oper-
ion. Proper layout of the area to be treated,
orough spotting, finishing the job before beetles
nerge, and constant attention to the quality of
e spray application are all absolutely necessary
obtain good results.

rections for Mixing and Applying Spray

Lindane spray is commonly prepared from a
percent emulsifiable concentrate. To get the
oper formulation combine No. 2 fuel oil (diesel
) and lindane concentrate at a ratio of 14:1.
x thoroughly by agitating the container or stir-
g the contents.

Apply the spray with a pressure-type garden
rayer or a knapsack sprayer. Use a nozzle that
oduces a coarse, cone-shaped spray. Spray the
infested portions of attacked trees uniformly and thoroughly. Apply spray only until the bark is thoroughly wet. It is wasteful and unnecessary to apply spray to the point of runoff.

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__________ and Swain, Kenneth M.
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USE PESTICIDES CAREFULLY

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions a heed all precautions on the labels.

Store pesticides in original containers under lock and key -- out of the reach of children and animals -- and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment i specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. I case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Becaus it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, o crush and bury them in a level, isolated place.

NOTE: *Some States have restrictions on the use of certain pesticides. Check your State and loca regulations. Also, because registrations of pesticides are under constant review by the U. S. Department of Agriculture, consult your county agricultural agent or State Extension specialist t be sure the intended use is still registered.*

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

U S D A FOREST SERVICE
RESEARCH NOTE RM-168

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Engelmann Spruce Seed Dispersal and Seedling Establishment in Clearcut Forest Openings in Colorado —

a progress report

Frank Ronco[1]

Results through the summer of 1967 are reported from five locations for periods up to 6 years. Good crops of 100,000 or more seeds per acre were produced only once in 4 or 5 years on three areas; elsewhere seed crops were good in 2 of 6 years. Seedfall into clearcut openings decreased rapidly beyond about 1.5 chains from standing timber, but considerable sound seed was still dispersed across openings in years of good seed production. In general, openings were stocked with less than 300 well-distributed trees per acre; seedling establishment appeared to be limited more by environmental factors that affect germination and survival than by seed supply.

Seedling survival and seed production data are eeded to estimate the amount of seed required r natural regeneration success under different nditions. Seed dispersal distances determine the e of clearcut opening that will adequately restock. nce Engelmann spruce (Picea engelmannii Parry)—balpine fir (Abies lasiocarpa (Hook.) Nutt.) forests ow under a wide range of environmental conditions, information obtained on seedfall and seedling survival in one area may not be applicable elsewhere. Consequently, studies were started in 1961 at five locations in the spruce-fir type in Colorado to determine the amount and frequency of seed crops, seed dispersal in relation to distance from source, and initial seedling survival. This Note summarizes the results through 1967.

Study Areas and Methods

Study areas were established in clearcuts on the Arapaho, Rio Grande, Routt, San Juan, and

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[1] *Silviculturist, Rocky Mountain Forest and nge Experiment Station, with central headarters maintained at Fort Collins, in cooperion with Colorado State University.*

White River National Forests (table 1). Cutover areas, except on the White River, were selected with the long axis of the cutting unit oriented at right angles to prevailing westerly and southwesterly winds. Since topography on the White River appeared to alter the prevailing wind direction, the cutover unit selected was oriented with respect to local winds.

Merchantable trees (10.0 inches d.b.h. and larger) on the areas were logged. Residual trees, including snags, that were large enough to provide an internal seed source or create eddy currents and obstructions in the glide path of seeds from surrounding timber stands were felled before seed traps were installed.

Quantity of seed produced and dispersal distances were measured with 1-foot-square wire seed traps described by Boe.[2] Traps were placed 0.5 chain apart in rows parallel to the long axis c the clearcut (fig. 1). Each row contained 10 traps but the number of rows on each Forest varied wit the width of the cutover (table 1). Trap installatio and location with reference to timber edges wer similar on each Forest.

Traps were initially installed only in the are logged, but in the summer of 1964 a row of 1 traps was placed 1 chain into uncut stands on th windward and leeward sides of openings.

Annual seed count data were summarized throug the summer of 1967, except on the Rio Grand National Forest where collections were discontinue after 1965. Seedfall was recorded in uncut stanc only in 1965 and 1966, but not enough seed wc caught in either year to make reliable estimate of seed production. In other years, estimates c seed production were based on the amount of seec fall at the edge of the clearcut openings.

Seedling survival was recorded on 1/300-acr circular plots established at each seed trap locatio within the cutover area (fig. 1). On three of th Forests—Arapaho, Rio Grande, and White River-

Table 1.--Description of Engelmann spruce seed dispersal and seedling establishment study areas on five National Forests in Colorado

National Forest and Ranger District	Drainage	Elevation	Year logged	Year study established	Size of cutover	Aspect	Slope	Rows of traps[1]
		Feet					Percent	Number
Arapaho								
Hot Sulfur	Stillwater Creek	10,400	1958	1961	2-chain contour strip	N70E	33	4
Rio Grande								
Saguache	California Gulch	10,800	1959	1961	4-chain contour strip	N70E	15	6
Routt								
Bears Ears	West Prong, South Fork Slater Creek	9,400	1961	1963	26-acre block	S37W	16	10
San Juan								
Dolores	Spring Creek (on Taylor Mesa)	10,200	1959	1962	32-acre block	N38E	5	15
White River								
Frying Pan	Rocky Fork Creek	11,100	1956	1961	4-chain contour strip	N20W	20	6

[1] Includes rows placed beneath uncut stands on the leeward and windward sides of openings.

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[2] *Boe, K. N. A one-foot-square wire seed trap. J. Forest. 53: 368-369. 1955.*

gging slash was removed manually from the plots th little disturbance of the seedbed. Plots were arified to some extent, however, in logging. On e Routt and San Juan study areas, where logging ash was piled with a tractor-mounted rake and rned, plots were heavily scarified.

All seedlings left on plots immediately after gging were removed, and only those seedlings at germinated after the study began were counted. ew seedlings were identified with plastic markers owing year of germination.

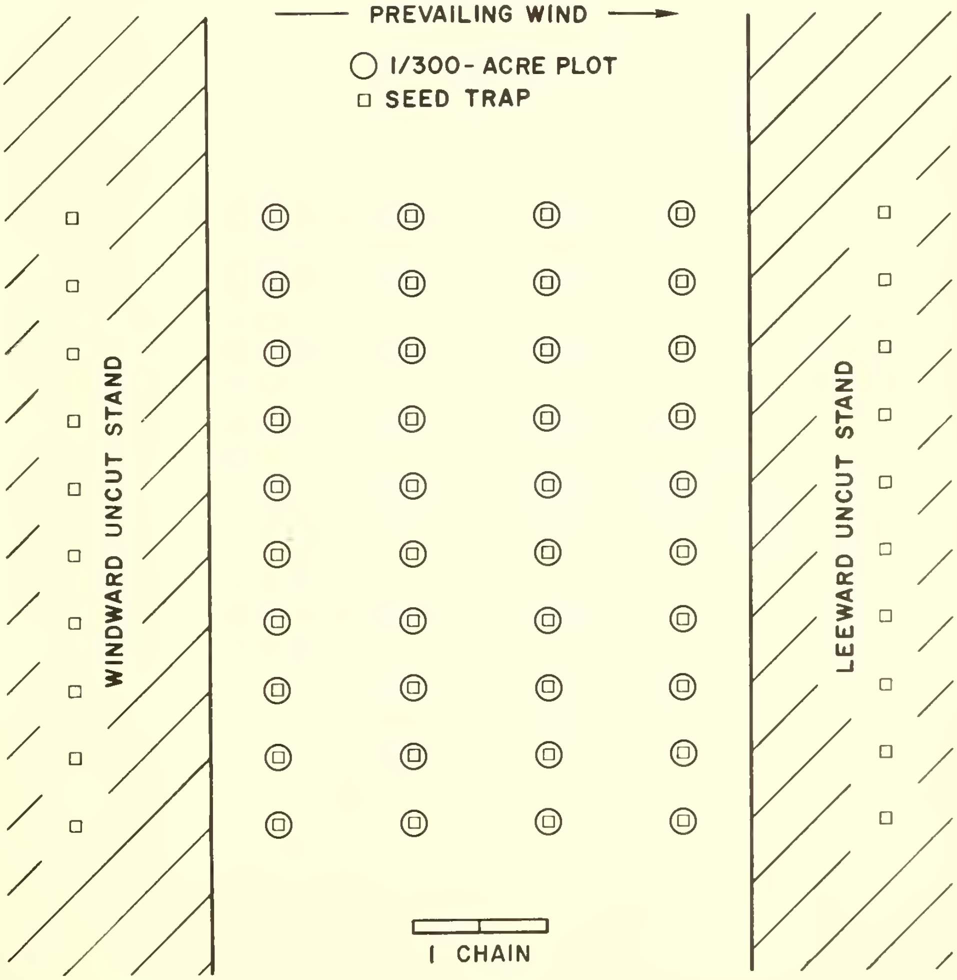
Results

eed Dispersal

Engelmann spruce seed production varied by year d location. Good seed crops—100,000 or more und seeds per acre—were most frequent on the Arapaho (1961 and 1963) and White River (1963 and 1964). Good crops were also produced on the Rio Grande and Routt in 1964, and on the San Juan in 1963. Moderate crops—50,000 to 100,000 sound seeds per acre—were produced on the Arapaho in 1964 and on the White River in 1961. In other years of observation, seed crops were poor to complete failures. Total seedfall into openings, and seedfall during individual years of moderate to good seed production, are shown for all Forests in figure 2.

In most years when seed was produced in significant amounts, seedfall was similar on all Forests. Seed dispersal into openings decreased as distance from source increased. Most seeds fell within 1.5 chains of standing timber.

Prevailing winds apparently influenced the pattern of seedfall on most Forests in years of significant production. Seedfall was greatest near the windward side of the openings, and diminished



gure 1.--Location of seed traps and seedling survival plots (1/300 acre) within a clearcut contour strip on the Rio Grande National Forest; study areas on other Forests were similar except for width of cutover opening.

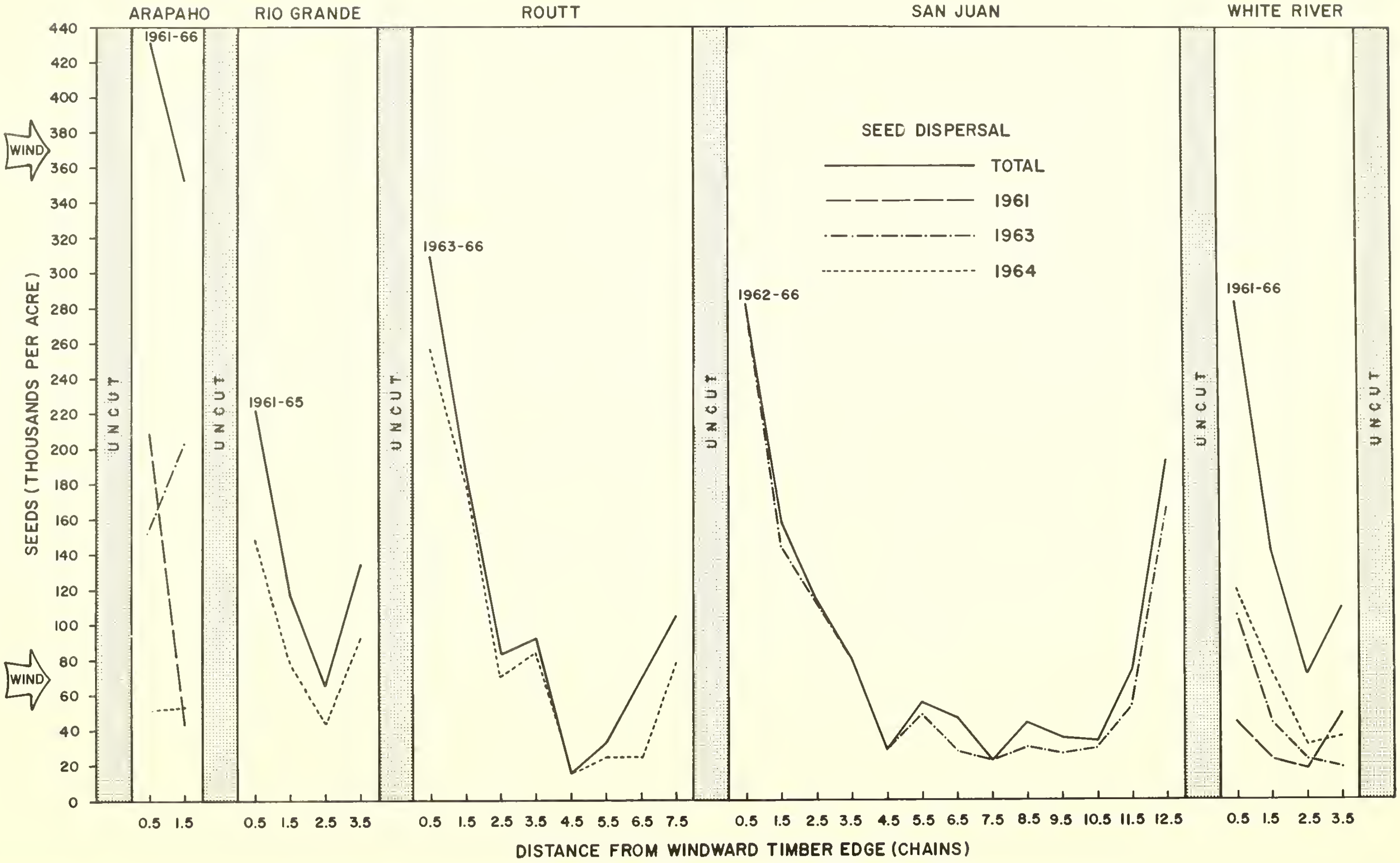


Figure 2.--Seed dispersal by distance from windward edge of clearcut openings on five National Forests for moderate to good seed years (1961, 1963, 1964),

teadily as distance increased to about 1/2 to 2/3 f the way across the openings, where the fewest eeds were caught—about 20 percent of the seedfall ear the windward edge. The influence of wind irection on dispersal patterns was variable in years f poor seed production, and in the smallest openngs (Arapaho) regardless of the quantity of seed roduced.

urvival of Seedlings

Number and stocking of seedlings in 1967 was elated to quantity of seedfall, distance from seed ource, and seedling age (fig. 3). Most seedlings ere found within 1.5 chains from seed source, ut no relationship could be established between umber of seedlings and location with respect to revailing winds. More seedlings were alive near he windward timber edge on the White River and outt, but on the San Juan and Rio Grande more live seedlings were found nearest the leeward timber stand.

Percentage of stocked 1/300-acre plots, shown in parentheses in figure 3, was also highest within 1.5 chains of standing timber, where seedlings were most abundant. Plots beyond about 1.5 chains were either poorly stocked or nonstocked.

Living seedlings were found on all Forests, but not all potential age classes were present on each Forest. The proportion of the total number of live seedlings within any age class also varied between Forests. In general, 2-year-old seedlings were most numerous and were found on all Forests. Fewer seedlings were recorded in the 3-year age class, but they were present on all Forests except the Arapaho. No 4-year-old seedlings were found, and only a few 5-year-old and 1-year-old trees were alive.

Survival of seedlings of all ages was poor on each Forest (table 2). Seedling mortality, which

Table 2.--Percentage survival of seedlings over all age classes at different distances from the windward edge of clearcut openings on five National Forests

Distance from windward edge of clearcuts (chains)	Survival by National Forest				
	Arapaho	Rio Grande	Routt	San Juan	White River
	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -
0.5	15	5	47	50	44
1.5	12	6	29	28	46
2.5	--	4	29	14	38
3.5	--	12	33	7	20
4.5	--	--	32	5	--
5.5	--	--	27	0	--
6.5	--	--	21	60	--
7.5	--	--	9	0	--
8.5	--	--	--	12	--
9.5	--	--	--	33	--
10.5	--	--	--	0	--
11.5	--	--	--	50	--
12.5	--	--	--	67	--

Note: "--" indicates not applicable.

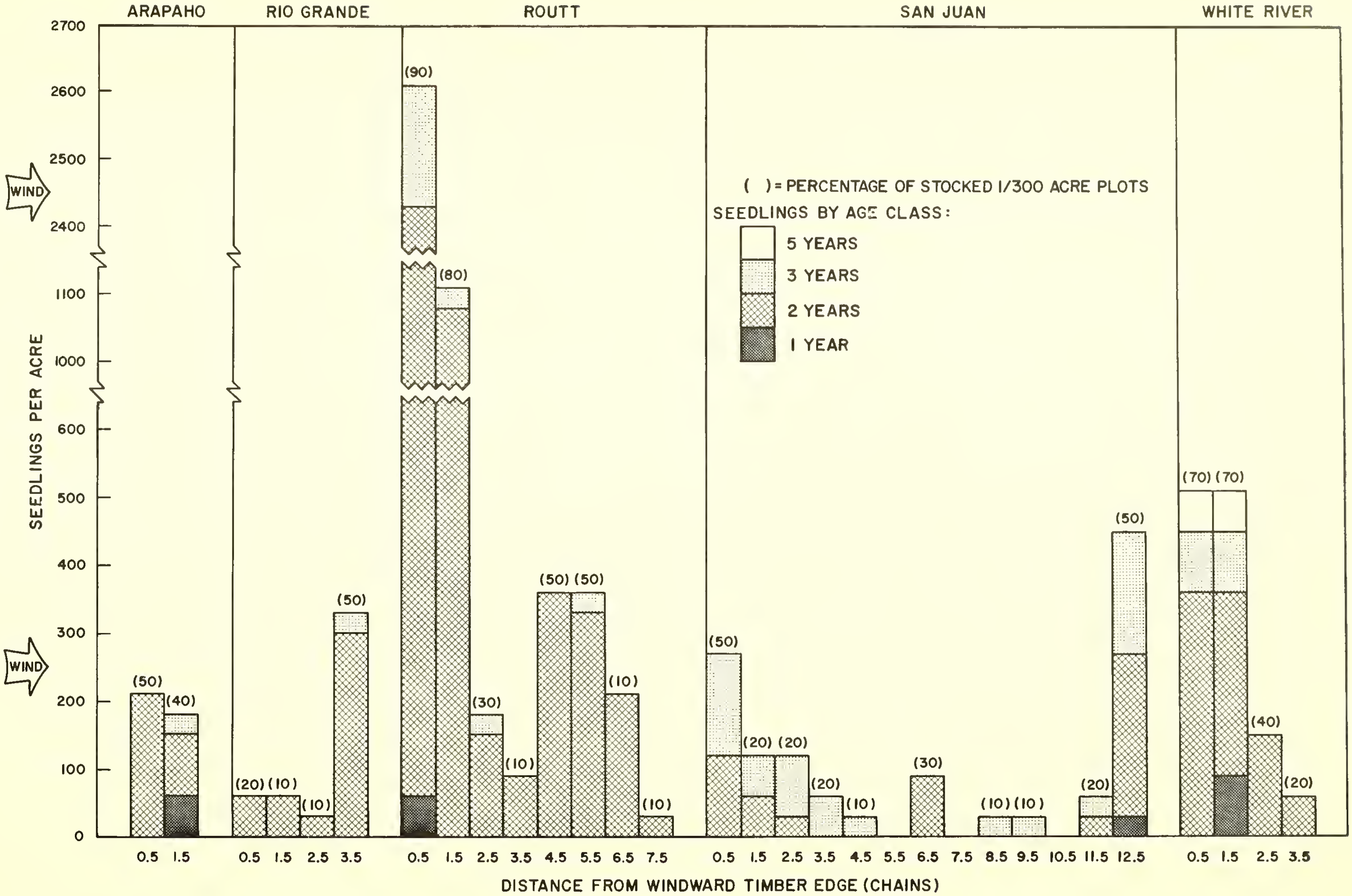


Figure 3.--Number of seedlings by age classes and percentage of stocked 1/300-acre plots (figures in parentheses) at different distances from the windward edge of clearcut openings on five National Forests. (Maximum possible age of seedlings:

as highest in the 1-year age class, decreased as edlings became older, but even 5-year-old seed-gs died.

Discussion and Conclusions

Seed was produced each year on all study areas, ut in most years the quantity was negligible. urthermore, good crops did not occur the same ear on all areas. Good crops were produced nly once in 4 or 5 years on the Rio Grande, Routt, nd San Juan National Forests. On the Arapaho nd White River, however, good crops were pro-uced in 2 of 6 years. Exceptionally good seed ops (1 million or more seeds per acre) as reported Roe[3] in Montana were not recorded in Colo-do during the period of observation; the last ch seed year observed in Colorado was 1952.

Even though seedfall decreased rapidly beyond out 1.5 chains from standing timber, considerable und seed was still dispersed across openings in ars of good seed production. Roe[3] and Squil- ce[4] found that large numbers of sound seed were spersed greater distances (7 to 10 chains) than reported here. They presented results from exceptional seed crops, however, and indicated that dispersal distances were not as great in years of lower seed production.

While seed in significant amounts fell into the openings beyond 1.5 chains, few seedlings became established beyond the margins of the openings. Regeneration success in the cutovers thus appeared to be limited more by adverse environmental factors than by seed supply. Exposure of seedlings to high light intensity and high temperatures, drying winds, and low temperatures and frost heaving contributed substantially to the poor survival in the openings.

Even near the margins of standing timber, where 300 or more seedlings per acre were alive, adequacy of regeneration is questionable because of the high mortality rate of young seedlings. Furthermore, the age at which those young seedlings can be considered to have a reasonable chance for survival cannot be determined now because losses have continued.

No recommendations can yet be made concerning the size opening that will restock to natural regeneration, the number of sound seeds needed to produce an established seedling, or total seed production required to adequately restock an area. Continuation of the study will provide information on seedling survival and establishment—including the age at which seedlings can be considered established—as well as additional data on the amount of seed produced, dispersal distances, and periodicity of seed crops.

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[3] *Roe, Arthur L. Seed dispersal in a mper spruce seed year. U.S. Forest Serv. s. Pap. INT-39, 10 p. 1967. Intermt. For- t and Range Exp. Sta., Ogden, Utah.*

[4] *Squillace, A. E. Engelmann spruce seed spersal into a clear-cut area. U.S. Dep. r. Forest Serv., Intermt. Forest and Range p. Sta. Res. Note 11, 4 p. 1954. (Ogden, ah)*

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As our Nation grows, people expect and need more from their forests--more wood; more water, fish and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U. S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

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- *Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.*
- *Managing and protecting the 187-million acre National Forest System.*

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 169

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Abert's Squirrels Prefer Mature Ponderosa Pine

David R. Patton and Win Green[1]

Measurements from 538 ponderosa pines with squirrel clippings underneath showed squirrels preferred trees 11 to 30 inches diameter, breast height. The smallest tree with clippings was 4 inches; the largest, 36. Average diameter of all trees used was 19 inches.

KEY WORDS: Sciurus aberti, Pinus ponderosa, forest-wildlife relations.

The Abert's squirrel (Sciurus aberti aberti Woodouse) is gaining in popularity as a small game nimal in Arizona. Statistics published by the Ariona Game and Fish Department show squirrel unters have increased from 6,071 in 1962 to 0,683 in 1969.[2]

In Arizona, the Abert's squirrel is restricted to ne ponderosa pine (Pinus ponderosa Lawson) forest t elevations from 5,500 to 8,500 feet, and is ependent on ponderosa pine for food and cover (fig. 1).[3] Ponderosa pine on commercial land in public ownership in Arizona amounts to 3,515,000 acres.[4]

Management of the Abert's squirrel under multiple use concepts depends upon a knowledge of its life history and habitat requirements. Life history and general habitat preferences have been documented by Keith.[3] This Note reports the results of a study to determine preference for tree size.

Figure 1.--Abert's squirrel habitat in ponderosa pine.

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[1] *Research Wildlife Biologists, located at empe, in cooperation with Arizona State Uniersity; the Station's central headquarters is t Fort Collins, in cooperation with Colorado tate University.*

[2] *Arizona Game and Fish Department. Ariona small game investigations. Tree squirrel anagement information. P-R Project W53R19-P3-J3. Reports for 1963-69.*

[3] *Keith, James O. The Abert squirrel and its dependence on ponderosa pine. Ecology 46: 150-163. 1965.*

[4] *Spencer, John S., Jr. Arizona's forests. U. S. Forest Serv. Resource Bull. INT-6, 56 p. Intermt. Forest and Range Exp. Sta., Ogden, Utah.*

Study Area

The Castle Creek watershed, where the study was conducted, is located at an elevation of approximately 8,000 feet, 12 miles southwest of Alpine, Arizona. Ponderosa pine, the dominant tree species on the watershed, is found in small groups of even-aged reproduction, saplings, poles, and sawtimber. Stands are irregularly spaced, characteristic of an all-aged forest.

The pine forest in Castle Creek watershed is typical of forest land between 7,500- and 8,500-foot elevation in the White Mountains. At the higher elevations it is close to the altitude of the mixed conifer, and has representative vegetatio that zone in the pine type. Douglas-fir (Pseudots menziesii (Mirb.) Franco), white fir (Abies conc (Gord. and Glend.) Lindl.), southwestern white p (Pinus strobiformis Engelm.), and quaking asp (Populus tremuloides Michx.) are found on the c moist, north-facing slopes.

Methods

The watershed was inventoried in 1964 by me of a systematic sample with random starts. Tr sects were installed with sample points spaced 440-foot intervals. Each transect had from 25 50 points, depending on transect length.

The inventory stakes were used as a refere to delineate a half-acre rectangular plot extend the distance between the sample points. Tr on the plots with squirrel cuttings underneath w recorded by diameter breast height (d.b.h.). Tr with squirrel nests were recorded without refere to plots or transects (fig. 2). Data were collec each October from 1964 to 1968.

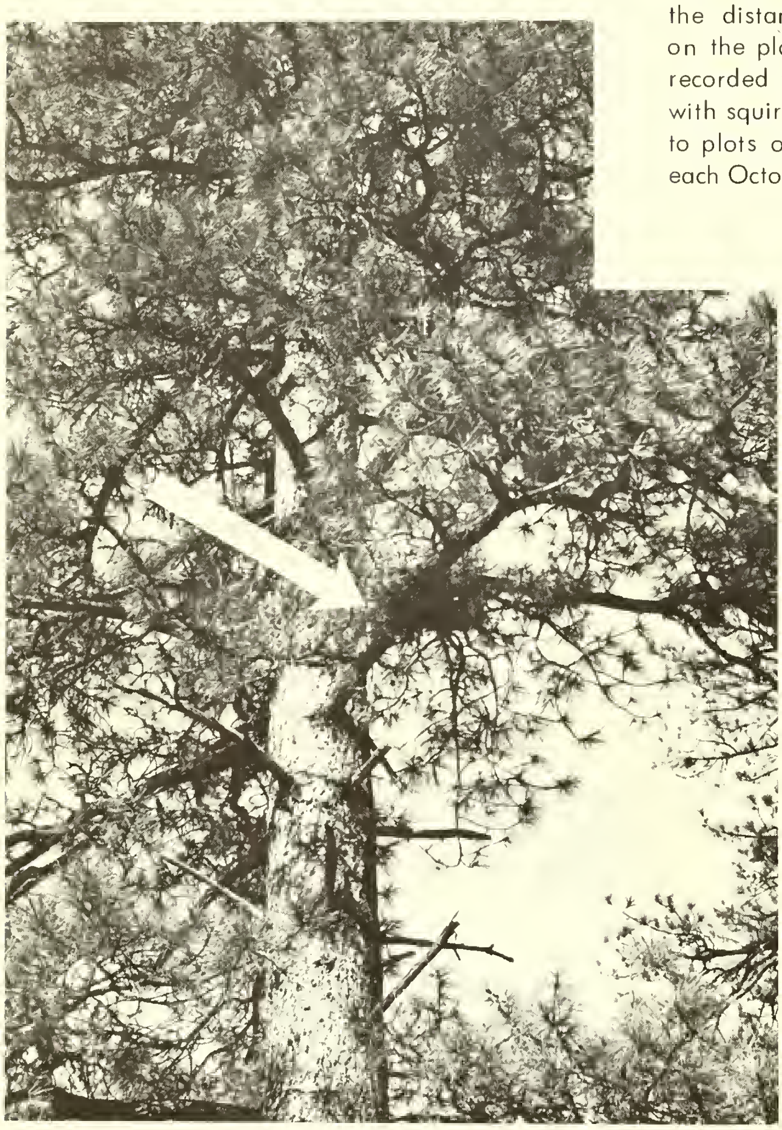

Figure 2.--Abert's squirrel leaf nest in a ponderosa pine.

Results

Of 538 ponderosa pines with squirrel cuttings underneath, the smallest tree was 4 inches, the argest was 36 inches, and the average of all trees with clippings was 19 inches d.b.h. A grouping in the 11- to 30-inch d.b.h. range accounted for 89 percent of the total trees used by the squirrels (table 1).

Squirrel nests made from leaves and branches were found in 10 ponderosa pines that averaged 17 inches d.b.h. The smallest tree with a leaf nest was 10 inches; the largest, 24 inches d.b.h. Smaller trees with nests generally were surrounded by larger, closely spaced trees. All nests were protected from above and to the side but not necessarily from below.

In four instances, squirrels were observed living in hollow Gambel oaks (Quercus gambelli Nutt.). All oaks were mature with over 10 inches d.b.h. Use of species other than ponderosa pine is not uncommon. Reynolds[5] recorded use of pinyon pine (Pinus edulis Engelm.) by the Abert's squirrels at Fort Bayard, New Mexico.

Table 1.--Frequency distribution of diameters from 538 ponderosa pines used by Abert's squirrels, Castle Creek watershed, 1964-68

Diameter class (Inches)	Number of trees used	Percent of total	
1 - 5	2	0.4	6.7
6 - 10	34	6.3	
11 - 15	87	16.2	89.6
16 - 20	206	38.3	
21 - 25	123	22.9	
26 - 30	66	12.2	
31 - 35	15	2.8	3.7
36 - 40	5	.9	
Total	538	100	

Management Implications

Although there is some use of other tree species, the Abert's squirrel is closely associated with and depends on ponderosa pine for food and cover. Data from Castle Creek watershed suggest squirrels are most closely associated with mature ponderosa pine in the range of 11 to 30 inches d.b.h. Thus, a segment of the Abert's habitat has been identified, at least tentatively.

Forest wildlife managers in the Southwest can use this basic information in conjunction with timber inventory data to prepare management plans. By delineating ponderosa pine stands in the 11- to 30-nch d.b.h. class on a type map, the preferred habitat of Abert's squirrels will be identified for that particular management unit.

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[5] *Reynolds, Hudson G. 1966. Abert's squirrel feeding on pinyon pine. J. Mammal. 47: 550-551. 1966.*

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U S D A FOREST SERVICE
RESEARCH NOTE RM-170

REST SERVICE
. DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Port-A-Punch[1] Recording and Computer Summarization of Pellet Count Data

David R. Patton and Wilson B. Casner[2]

Data are punched manually, directly on perforated computer cards, in the field. When a large number of deer and elk pellet plots are to be counted, the system will reduce office work and eliminate many errors from transposed figures. A Fortran computer program is presented which summarizes and prints the most common factors associated with pellet counts. No statistical tests are made in the program, but parameters for such tests are available from the computer printout. An average deck of 500 cards costs approximately $3 to run.

KEY WORDS: Programming (computers), elk, deer, wildlife management, Port-A-Punch, Fortran

Wildlife research and management biologists eed fast and efficient methods of recording and ummarizing pellet count data. Much time is lost transferring information from field forms to office omputation forms or computer cards. One efficient ethod is to record data directly on perforated omputer cards at the time data are collected in e field.[3] The system includes a punch board, transparent template, data card, and stylus (fig. 1). A magazine attached to the back of the board provides space for storing 50 data cards.

Description of the equipment items and costs are:

Description	Cost (July 1969)
Port-A-Punch (IBM) board with template and stylus	$12.75
Port-A-Punch magazine	2.50
Port-A-Punch cards, blank	4.00/M

Figure 1.--Port-A-Punch board with data card punched. Plot number 532 contains 1 deer and 3 elk groups.

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[1] *Trade and company names are used for the enefit of the reader and do not imply endorse- ent or preferential treatment by the U. S. epartment of Agriculture.*

[2] *The authors are, respectively, Research ildlife Biologist and Computer Programmer, lo- ated at Tempe, in cooperation with Arizona tate University; central headquarters is main- ained at Fort Collins, in cooperation with olorado State University.*

[3] *Giles, Robert H., Jr. [Ed.] Wildlife man- gement techniques. Ed. 3. 623 p. 1959. Wash. . C.: Wildlife Soc.*

The standard computer card contains 80 columns, but the Port-A-Punch card has 40 data columns numbered 2,4,6,8. . .80. Cards can be printed with factors to be punched on the card, or a plain card can be used with factors marked on the transparent template. Press-on letters can be applied on the template and will stay attached when sprayed with plastic.

A Fortran IV source program and input data format has been designed for the Port-A-Punch card to summarize the most common factors associated with deer and elk fecal pellet counting. Cost of running a program will vary with the type of computer and the number of data cards. An average deck with 500 cards should cost approximately $3 to run. The cost includes the computer reading the program, calculating the factors, and printing the results.

General Field Technique

Data cards are inserted in the board so the perforated rectangles line up with the holes in the template. To enter data on the card, the stylus is used to punch out perforations in the proper column and row (fig. 1). An unpunched number is automatically read as zero. The first two rows (zone punch) of the card are not used. Data cards for the program presented in this Note must be punched in the following manner:

Column	Port-A-Punch card with 40 columns
2-4-6-8;	Plot number (0001 to 9998)
10-12;	Number of deer groups (1 to 99)
14-16;	Number of elk groups (1 to 99)

The number 9999 is used as a control card; therefore, there cannot be a plot numbered 9999.

Once the cards have been punched, they can be used in several ways. The primary use is as a data deck in a computer program to summarize the information or analyze it statistically. Cards also can be run through a lister to obtain a printout of the data on each card. A printout is useful in checking for errors.

Office Technique

A Fortran source program for the GE-400 series computer to summarize deer and elk pellet count data is shown below. With modification, the program can be used in other machines. Some constants used in calculations may change with application. Those most likely to change are referenced by line number (extreme left of listing) and explained at the end of the program.

FORTRAN SOURCE PROGRAM

```
 1        DIMENSION ND(2500),NE(2500),DEER(2500),ELK(2500),KD(22),KE(22),KDC
         1HK(22),KECHK(22),WSHD(6)
 2     60 DO 104 I=1,22
 3        KD(I)=0
 4        KE(I)=0
 5    104 CONTINUE
 6        READ 2,N,WSHD,T,PLTSZ
 7      2 FORMAT (I4,6A4,F4.3,F5.5)
 8        IF (N.EQ.9999) GO TO 99
 9        EN=N
10        DO 6 I=1,N
11        READ 1,NPLT,ND10,ND1,NE10,NE1
12      1 FORMAT (I4,5X,I1,1X,I1,1X,I1,1X,I1)
13        IF (NPLT-9999) 91,90,90
14     90 IND=N-I+1
15        KD(1)=KD(1)+IND
16        KE(1)=KE(1) + IND
17        GO TO 92
```

```
  91 ND(I)=10*ND10+ND1
     NE(I)=10*NE10+NE1
     DEER(I)=ND(I)
     KDCHK(1)=0
     IF (ND(I)-KDCHK(1)) 61,61,62
  61 KD(1)=KD(1)+1
     GO TO 101
  62 DO 105 J=2,21
     K=J-1
     KDCHK(J)=KDCHK(K)+1
     IF (ND(I).EQ.KDCHK(J)) GO TO 63
 105 CONTINUE
     KD(22)=KD(22)+1
     GO TO 101
  63 IND=J
     KD(IND)=KD(IND)+1
 101 ELK(I)=NE(I)
     KECHK(1)=0
     IF (NE(I)-KECHK(1)) 64,64,65
  64 KE(1)=KE(1)+1
     GO TO 6
  65 DO 106 J=2,21
     K=J-1
     KECHK(J)=KECHK(K)+1
     IF (NE(I).EQ.KECHK(J)) GO TO 66
 106 CONTINUE
     KE(22)=KE(22)+1
     GO TO 6
  66 IN=J
     KE(IN)=KE(IN)+1
   6 CONTINUE
  92 SD=0.0
     SD2=0.0
     INDL=I-1
     IF (I.EQ.N) INDL=I
     DO 13 I=1,INDL
     SD=SD+DEER(I)
  13 SD2=SD2+DEER(I)**2
     AVED=SD/EN
     VARD=(EN*SD2-SD**2)/(EN*(EN-1.0))
     SYD=SQRT(VARD/EN)
     DPGPA=SD/(EN*PLTSZ)
     DCLIO=SYD*T*(1.0/PLTSZ)
     DPS=DPGPA*.13487
     CLDPS=DCLIO*.13487
     DDUPA=DPS*.57031
     CLDDU=CLDPS*.57031
     SE=0.0
     SE2=0.0
     DO 26 I=1,INDL
     SE=SE+ELK(I)
  26 SE2=SE2+ELK(I)**2
     AVEE=SE/EN
```

```
      VARE=(EN*SE2-SE**2)/(EN*(EN-1.0))
      SYE=SQRT(VARE/EN)
      EPGPA=SE/(EN*PLTSZ)
      ECLIO=SYE*T*(1.0/PLTSZ)
      EPS=EPGPA*.13487
      CLEPS=ECLIO*.13487
      EDUPA=EPS*.57031
      CLEDU=CLEPS*.57031
      PRINT 32,WSHD
   32 FORMAT ("1",33X,"COMPILATION AND PRELIMINARY ANALYSIS OF DEER-ELK
     1GROUPS",10X,"WATERSHED  ",6A4)
      PRINT 33,N,T,PLTSZ
   33 FORMAT    (//10X,"N = ",I4,3X,"T = ",F5.3,3X,"PLOT SIZE = ",F6.5,"
     1 ACRE")
      PRINT 34,SD
   34 FORMAT    (10X,"SUM OF DEER GROUPS",27X," = ",F12.2)
      PRINT 35,AVED
   35 FORMAT    (10X,"AVERAGE OF DEER GROUPS",23X," = ",F12.2)
      PRINT 37,VARD
   37 FORMAT    (10X,"VARIANCE OF DEER GROUPS",22X," = ",F12.2)
      PRINT 38,SYD
   38 FORMAT    (10X,"STANDARD ERROR OF DEER GROUPS",16X," = ",F12.2)
      PRINT 39,DPGPA
   39 FORMAT    (10X,"DEER GROUPS/ACRE",29X," = ",F12.2)
      PRINT 40,DCLIO
   40 FORMAT    (10X,"CONFIDENCE LIMITS FOR DEER GROUPS/ACRE",7X," = ",F
     112.2)
      PRINT 41,DPS
   41 FORMAT    (10X,"DEER/SECTION",33X," = ",F12.2)
      PRINT 42,CLDPS
   42 FORMAT    (10X,"CONFIDENCE LIMITS FOR DEER/SECTION",11X," = ",F12.
     12)
      PRINT 43,DDUPA
   43 FORMAT    (10X,"DEER DAYS USE/ACRE",27X," = ",F12.2)
      PRINT 44,CLDDU
   44 FORMAT    (10X,"CONFIDENCE LIMITS FOR DEER DAYS USE/ACRE",5X," = "
     1,F12.2)
      PRINT 45,N,T,PLTSZ
   45 FORMAT    (/10X,"N = ",I4,3X,"T = ",F5.3,3X,"PLOT SIZE = ",F6.5,"
     1ACRE")
      PRINT 46,SE
   46 FORMAT    (10X,"SUM OF ELK GROUPS",28X," = ",F12.2)
      PRINT 47,AVEE
   47 FORMAT    (10X,"AVERAGE OF ELK GROUPS",24X," = ",F12.2)
      PRINT 48,VARE
   48 FORMAT    (10X,"VARIANCE OF ELK GROUPS",23X," = ",F12.2)
      PRINT 49,SYE
   49 FORMAT    (10X,"STANDARD ERROR OF ELK GROUPS",17X," = ",F12.2)
      PRINT 50,EPGPA
   50 FORMAT    (10X,"ELK GROUPS/ACRE",30X," = ",F12.2)
      PRINT 51,ECLIO
```

```
116    51 FORMAT    (10X,"CONFIDENCE LIMITS FOR ELK GROUPS/ACRE",8X," = ",F1
         12.2)
117         PRINT 52,EPS
118    52 FORMAT    (10X,"ELK/SECTION",34X," = ",F12.2)
119         PRINT 53,CLEPS
120    53 FORMAT    (10X,"CONFIDENCE LIMITS FOR ELK/SECTION",12X," = ",F12.2
         1)
121         PRINT 54,EDUPA
122    54 FORMAT    (10X,"ELK DAYS USE/ACRE",28X," = ",F12.2)
123         PRINT 55,CLEDU
124    55 FORMAT    (10X,"CONFIDENCE LIMITS FOR ELK DAYS USE/ACRE",6X," = ",
         1F12.2)
125         PRINT 83
126    83 FORMAT(///,40X,"FREQUENCY DISTRIBUTION - DEER GROUPS/PLOT")
127         PRINT 84
128    84 FORMAT  (//,9X,"NO. OF GROUPS/PLOT",5X,"0",3X,"1",3X,"2",3X,"3",3X
         1,"4",3X,"5",3X,"6",3X,"7",3X,"8",3X,"9",2X,"10",2X,"11",2X,"12",2X
         2,"13",2X,"14",2X,"15",2X,"16",2X,"17",2X,"18",2X,"19",2X,"20",2X,"
         3GT 20")
129         PRINT 85,(KD(I),I=1,22)
130    85 FORMAT    (/,9X,"NO. OF PLOTS",8X,21(1X,I3),3X,I3)
131         PRINT 86
132    86 FORMAT(///,40X,"FREQUENCY DISTRIBUTION - ELK GROUPS/PLOT")
133         PRINT 84
134         PRINT  85,(KE(I),I=1,22)
135         GO TO 60
136    99 PRINT 999
137   999 FORMAT (//"END OF JOB")
138         CALL EXIT
139         END
```

The value .13487 in cards numbered 61, 62, 5 and 76 and .57031 in cards numbered 63, 64, 7 and 78 may change because they represent he relationship between animals per section per ear and pellet groups per acre per year. Varibles are inserted on a header card placed in front f the data deck. Header cards are punched in the ollowing manner:

Column	Standard Card With 80 Columns
1 to 4	Number of plots (1 to 9998)
5 to 28	Identification (24 letters or less)
29 to 32	"t" value (decimal is not punched on the card but the computer has been programmed to place the decimal after the 1st digit).
33 to 37	Plot size (.00001 to .99999), decimal is not punched.

The source program presented here was written for 2,500 plots. To change the number of plots, the number in parentheses in the dimension statement (card number 1 in the program) is changed.

The source program will summarize the data and a printout will show factor values as in the following example:

```
          COMPILATION AND PRELIMINARY ANALYSIS OF DEER-ELK GROUPS

                     WATERSHED WILLOW CREEK EAST FORK

N =  182    T = 1.653   PLOT SIZE = .00300 ACRE
SUM OF DEER GROUPS                             =        26.00
AVERAGE OF DEER GROUPS                         =         0.14
VARIANCE OF DEER GROUPS                        =         0.20
STANDARD ERROR OF DEER GROUPS                  =         0.03
DEER GROUPS/ACRE                               =        47.62
CONFIDENCE LIMITS FOR DEER GROUPS/ACRE         =        18.29
DEER/SECTION                                   =         6.42
CONFIDENCE LIMITS FOR DEER/SECTION             =         2.47
DEER DAYS USE/ACRE                             =         3.66
CONFIDENCE LIMITS FOR DEER DAYS USE/ACRE       =         1.41

N =  182    T = 1.653   PLOT SIZE = .00300 ACRE
SUM OF ELK GROUPS                              =         1.00
AVERAGE OF ELK GROUPS                          =         0.01
VARIANCE OF ELK GROUPS                         =         0.01
STANDARD ERROR OF ELK GROUPS                   =         0.01
ELK GROUPS/ACRE                                =         1.83
CONFIDENCE LIMITS FOR ELK GROUPS/ACRE          =         3.03
ELK/SECTION                                    =         0.25
CONFIDENCE LIMITS FOR ELK/SECTION              =         0.41
ELK DAYS USE/ACRE                              =         0.14
CONFIDENCE LIMITS FOR ELK DAYS USE/ACRE        =         0.23


            FREQUENCY DISTRIBUTION - DEER GROUPS/PLOT
NO. OF GROUPS/PLOT    0   1  2  3  4  5  6  7 .....20
NO. OF PLOTS        162  15  4  1  0  0  0  0 ..... 0

            FREQUENCY DISTRIBUTION - ELK GROUPS/PLOT

NO. OF GROUPS/PLOT    0  1  2  3  4  5  6  7 ......20
NO. OF PLOTS        181  1  0  0  0  0  0  0 ...... 0
```

Many data decks can be processed at the same me. Each deck contains a header card and a ontrol card consisting of the number 9999 following e last data card. The 9's card is punched on the andard card in columns 1 to 4. To end the program two 9's cards are required after the last data card in the final deck. A typical setup for two data decks is shown in figure 2.

The formulas used to summarize the data are found in any statistics text. No statistical tests are made in the program, but the parameters are available for such tests.

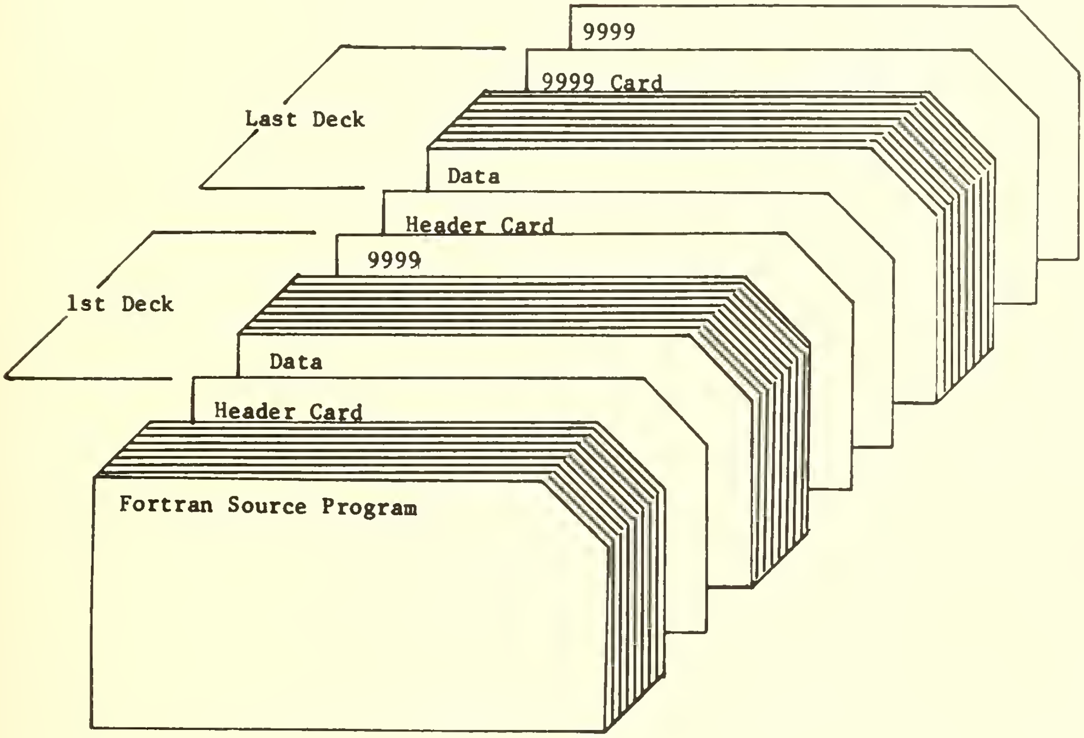

Figure 2.--Data deck set up for insertion in the computer (minus control cards necessary for run on a specific computer).

About The Forest Service. . . .

As our Nation grows, people expect and need more from their forests—more wood, more water, fish and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U. S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- *Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.*
- *Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.*
- *Managing and protecting the 187-million acre National Forest System.*

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 171

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

MITES ASSOCIATED WITH *IPS* AND *DENDROCTONUS* IN SOUTHERN ROCKY MOUNTAINS

With Special Reference to *Iponemus truncatus* (Acarina: Tarsonemidae)[1]

Gary D. Boss and T. O. Thatcher

No mites attacked any stage of the Dendroctonus beetles. Mites of the genera Iponemus Lindquist and Digamasellus Berlese were predaceous on the eggs of Ips. Iponemus truncatus (Ewing) females completed their life cycle in 8.7 days. Female mites overwintered in the egg niches of the beetles and fed on phloem sugar, bacteria, and yeast, but required predation on beetle eggs for reproduction. Each mite fed on one beetle egg and produced about 75 eggs.

KEY WORDS: *Iponemus truncatus*, *Ips* spp., *Dendroctonus* spp., mites, Scolytidae.

The importance of predatory mites in controlling
rk beetles is poorly understood. Rust (1933)
ported *Ips pini* (Say) egg mortality of 10 to 85
rcent caused by *Parasitus* sp. and possibly an
onemus sp. In California, Lindquist and Bedard
961) found four species of *Tarsonemoides* (Tar-
nemidae) feeding on four species of *Ips*. Lind-
ist (1964, 1969) reported additional species of
onemus (=*Maseria*=*Tarsonemoides*) on other *Ips* spp. in North America, Europe, and Asia. *Iponemus typographus* (L.), a European species, completes its life cycle within 2 weeks under field conditions (Balazy and Kielczewski 1965) while *Iponemus confusus*, an American species, can complete its life cycle within a week under laboratory conditions (Lindquist and Bedard 1961). The studies described here were conducted to obtain basic information on identity, behavior, and role of mites affecting bark beetles in the southern Rocky Mountain area.

Methods

Bark beetles to be examined for mites were collected from the following areas: mountain pine beetles, *Dendroctonus ponderosae* Hopkins, from *Pinus ponderosa* Laws. near Red Feather Lakes, Colorado and Lead, South Dakota; spruce beetles, *Dendroctonus rufipennis* (Kirby) from *Picea engelmannii* Parry near Beulah, near Gould, and near

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[1] From a thesis submitted by the senior
thor in partial fulfillment of the require-
nts for his M.S. degree at Colorado State Uni-
rsity. This research was supported by Grant
. 16-102 of the Rocky Mountain Forest and
nge Experiment Station, USDA Forest Service,
th central headquarters maintained at Fort
llins, in cooperation with Colorado State Uni-
rsity. Boss is Graduate Research Assistant,
partment of Forest and Wood Science, and
atcher is Professor, Department of Entomology,
lorado State University.

Red Feather Lakes, Colorado. *Ips calligraphus* (Germar) and *I. plastographus* (Lec.) were collected near Castle Rock, Colorado; *I. knausi* Swaine near Castle Rock and Lyons, Colorado; *I. pini* from several locations in Larimer County, Colorado, all from *P. ponderosa*. *I. confusus* [2] (Lec.) were collected in *Pinus edulis* Engelm. near Cuba, New Mexico; *I. borealis* Swaine in *Picea glauca* (Moench) from Cheyenne Crossing, South Dakota; and *I. pilifrons* Swaine in *Picea engelmannii* near Gould, Colorado.

Mites were collected from the beetles, from the beetle galleries, or by Newell's (1955) method with Berlese funnels. Mites were reared in plastic vials containing plaster-of-paris by the method described by Woodring (1953). Phloem sections, 1/4 inch square, were placed in some of the vials. Most of the observations on life cycles of the adult and the behavior of the larvae of *Iponemus truncatus* were made on the phloem sections in the vials, with a few made in the bark beetle egg niche. The vials were held in a desiccator containing a saturated solution of potassium sulfate according to the method of Wiston and Bates (1960).

Three potential methods of supplementary feeding were investigated, and each was periodically examined to determine whether the mites fed:

1. Cultures of fungi that commonly occur in galleries were established and stained with Rhodamine B fluorescent dye; mites were allowed to feed in cultures for 2 days, then were examined for internal fluorescence.
2. Living mite-infested beetles were pinned, then yeast and bacteria from beetle galleries were placed on the scutellum.
3. Living mite-infested beetles were pinned, then a paste of ground sucrose, honey, and Rhodamine B dye was applied to the scutellum.

Results and Discussion

Representatives of 11 families and 12 genera of mites were identified from the beetles and galleries (table 1).

Only three mite groups were observed as being predaceous, and those only on *Ips*. Two deutonymphs of a *Digamasellus* sp. (fig. 1) were seen leaving the egg niches of *Ips pilifrons* in whic the beetle eggs were partially consumed. Althoug the mites were not actually observed feeding o the eggs, it is believed that they had been feedin as the other eggs in the gallery were norma *Mexacheles* sp. (fig. 2) were seen preying on th hypopi of *Histiogaster arborsignum* Woodring. Th predation was observed several times in the beetl galleries, and was also duplicated by isolatin *Mexacheles* sp. with hypopi. The predation rat was about two hypopi per hour in the isolatior *Iponemus* sp. were seen preying on the eggs c all *Ips* examined.

Table 1.--Mites associated with seven specie of *Ips* and two species of *Dendroctonus* fro southern Rocky Mountains

Mites	Bark beetles								
	Ips borealis	*I. calligraphus*	*I. confusus*	*I. knausi*	*I. pilifrons*	*I. pini*	*I. plastographus*	*Dendroctonus rufipennis*	*D. ponderosae*
PREDACEOUS:									
Iponemus truncatus						x	x		
I. calligraphi cordillerae		x		x					
I. confusus			x						
I. gaebleri	x				x				
Digamasellus sp.	x	x	x		x	x			
Mexacheles sp.			x			x			x
NONPREDACEOUS:									
Eugamasus sp.	x	x		x	x	x	x		
Hypoaspis sp.				x	x				
Leiodinychus sp.	x	x	x	x	x	x	x		x
Proctolaelaps sp.		x	x	x	x	x			x
Erynetoides sculutis		x	x	x	x	x	x	x	x
Pygmephorus sp.		x	x	x	x	x	x		
Tarsonemus sp. #1					x				
Tarsonemus sp. #2		x		x	x	x	x		
Histiogaster arborsignum				x		x			x
Histiostoma sp.	x								

---

[2] *At the time of collection, correct identity of species involved was questioned; I. confusus has since been verified (Lanier 1970).*

Figure 1.--*Digamasellus* sp., presumed to be a predator on eggs of *Ips pilifrons*.

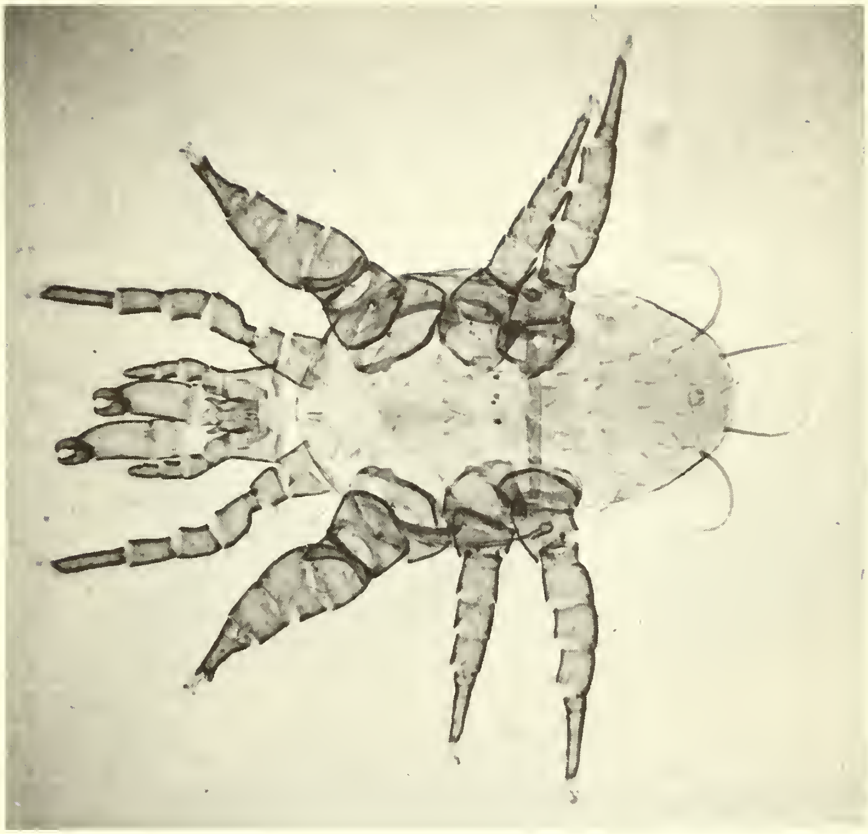

Figure 2.--*Mexacheles* sp., a predator of hypopi of *Histiogaster arborsignum*.

With the exception of the three predaceous mite groups mentioned, all other groups were found to be phoretic on the beetle, but showed no evidence of predation. *Pygmephorus* sp. (fig. 3) displays a peculiar phoretic behavior: mites attach themselves to the setae in the gular region and to the femoral and tibial setae on the legs of *Ips*. After the beetle attacks, the mites leave it and apparently feed on the yeasts or bacteria in the galleries. When engorged the mites resemble colonies of yeast (fig. 4).

Mites located in the galleries of *Ips pini* during the winter months were *Leiodinychus* sp., *Tarsonemus* sp. No. 2, *Erynetoides sculutis* Hunter, and *Iponemus truncatus*. The former two species were found only occasionally, but the latter two occurred frequently. All stages of *E. sculutis* occurred simultaneously in the open beetle galleries. In one gallery, 14 eggs were found scattered singly adjacent to a pitch pocket. The only food source that appeared available was the phloem sugars and micro-organisms on the phloem and frass. Fully fed but unengorged *I. truncatus* females were frequently found in the egg niches. No males were found.

No mites were found feeding on any stage of the two species of *Dendroctonus*. The mites probably cannot reach the eggs, larvae and pupae because the galleries are tightly packed with frass, except for the short period between oviposition and covering of the egg with frass. *Dendroctonus* are used by the mites only for dissemination. The mites' activities under the bark during the period of brood development are unknown, but it is believed that they feed on phloem sugars, bacteria, and yeast.

Mites of the genus *Iponemus* were predaceous on the eggs of all the species of *Ips* examined. These mites are phoretic in the beetle declivity. *Iponemus truncatus* was common to *Ips pini* and *I. plastographus*. *Iponemus gaebleri* (Schaarschmidt) was associated with *Ips borealis* and *I. pilifrons*. *Iponemus calligraphi cordillerae* Lindquist was associated with *Ips knausi* and *I. calligraphus*. *Iponemus confusus* (Lindquist and Bedard) was allied with *Ips confusus*.

The biology of *Iponemus truncatus* was studied in detail. The life cycles of the other three *Iponemus* species were similar. Upon hatching, the larvae are pale white and wrinkled. In the rearing containers, they immediately began to move about on the phloem section, on other mite eggs, and on the engorged female. If a phloem section was present, the larvae wandered about on it until they matured into adults. While the larvae wander, they may feed on phloem sugars, bacteria, and yeast.

The larvae matured and were fully expanded after an active period of about 30 hours. They wandered about on the phloem section and the engorged female, and eventually passed into the "quiescent larval" stage. The "quiescent larvae" did not molt between active and the motionless quiescent stages. This latter stage transformed from larva to adult in about 90 hours. No adult emerged when the phloem section was absent. Failure to emerge as an adult is thought to be due to a nutritional shortage during the larval stage When mite eggs were isolated on the plaster base the newly emerged larvae immediately disperse and disappeared into the air pores in the plaster making observations impossible.

There was no external morphological indicatio of which sex was developing, but an identifiabl outline of the adult was visible within th "quiescent larval" exoskeleton before emergence The "quiescent larva" was attached to the sur rounding phloem or cambial layer by the larva mouthparts, and/or the propodosomal legs. Fo the first 2 to 3 days, the larva was firmly attache to the layers, but after this period, it was dislodge and carried by the male mite.

Less than 5 percent of the total mature broo were males. As adults, males live only 3 to 4 day usually in the immediate vicinity of the emergin females. The males emerge after 7.7 days, or abou 1 day earlier than the females. This is though to be necessary for the males to reach sexu maturity. Sperm transfer between mature adul was not observed. Males were seen carrying th developing female "quiescent larvae" between the fourth pair of legs. Apparently the male can dete mine the sex of the "quiescent larva" prior t emergence.

The adult female is the most active of the motil stages. Immediately upon hatching the femal disperse from the open egg niche. If the egg nic is closed, the mites cannot disperse until it opened either by beetle feeding, or by shrinkag or peeling of the bark. Only one parthenogenet female was observed, the progeny being all male Females dispersed rapidly when a high populati of nematodes was present on the phloem. Dispers was also hastened by intense light and heat.

Figure 3.--*Pygmephorus* sp. attached to tibia of *Ips pini*.

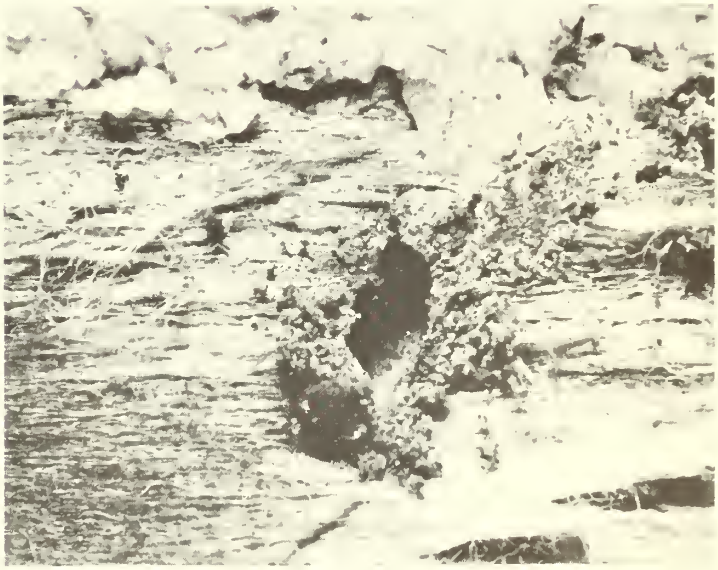

Figure 4.--Engorged *Pygmephorus* females resembling colonies of yeast in *Ips* beetle gallery.

Only female mites were phoretic on the beetles. The exact time the mite attaches itself to the beetle is unknown, but it is believed that attachment occurs only a short time before the beetle emerges, as mites were never found on teneral adults. The majority of the mites were associated with the adult beetles which emerged first from a particular brood. As the emergence of the beetles continued, fewer mites could be found on the beetles; those beetles which emerged last often had no mites attached to them. Undisturbed mites remained in the beetle declivity, but when disturbed they would disperse upon the beetle, eventually resettling in the declivity.

After the beetle starts constructing the gallery, the phoretic mites leave, in search of beetle eggs. It is probable that only those eggs located by the mites before they are sealed off by frass are preyed upon. Mites attack the beetle eggs and begin engorging within 4 days after the initial beetle attack (fig. 5). Only twice were two or more mites found on one beetle egg. Feeding completely consumes the beetle egg in 4 to 5 days. A mite begins ovipositing on the second day of feeding and continues for 4 days. After feeding ceases, oviposition continues for about 1 day after which the mite dies. The mean number of eggs deposited per female was 106 (range 86 to 128). Several times when the parasitized beetle egg was being removed, the mites were dislodged. Attempts to reposition these mites failed except in one case; the mite was not fully engorged and was able to reposition itself on the beetle egg and continue feeding.

Under environmental conditions of 27°C. and 97 percent relative humidity the larval mite hatches from the egg in an average of 50.2 hours (range 44.7 to 56.3 hours).

Attempts to culture mites on fungi, yeasts, and bacteria from the beetle galleries, or on honey and sucrose were unsuccessful. The mites did not appear to feed on the fungi; they were very active, and never settled in one location or attempted to feed. No fluorescence which would have resulted from feeding on stained substances could be detected.

It was not determined whether the yeast o bacteria was preferred, but mites in the declivity would migrate and congregate around the supposed food material.

Fewer mites congregated around the sucrose-honey paste, but it was possible to detect fluorescence in the gut of only one mite. The mites normally possess a brilliant yellow-green autofluorescence easily distinguishable from the Rhodamine B. From these latter two behavorial patterns indications are that the mites do feed in addition to the predation on the beetle eggs.

Figure 5.--A, engorging and ovipositing female of *Iponemus truncatus*; B, partially consumed egg of *Ips pini*; C, mite egg.

Acknowledgment

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 172

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERI ENT STATIO

Sequential Thinnings Boost Productivity of a Ponderosa Pine Stand in the Black Hills of South Dakota

Charles E. Boldt[1]

Two thinnings in rapid sequence--the first moderate, the second severe, 7 years later--transformed a stagnant stand of ponderosa pine saplings into a thrifty stand of small sawtimber in only 11 years. The drastic second thinning entailed no loss of volume production, but resulted in unusually rapid rates of individual tree growth for the Black Hills--perhaps near the potential for good sites. Intensified thinning practice may prove desirable and justifiable in certain management situations.

KEY WORDS: Thinning (trees), forest improvement cutting, Pinus ponderosa.

It is impossible to produce merchantable crops f ponderosa pine (Pinus ponderosa Laws.) timber n a reasonable rotation in the Black Hills without xercising some control over growing stock density. ome research and much experience have conincingly demonstrated a need for an extensive rogram of stand density control, normally entailing ne precommercial and three or four commercial innings during the life of a sawtimber crop.

More intensive thinning programs are being sed successfully in other forest regions to hasten mber stand development, shorten crop rotations, nd increase forest productivity. Knowing this, Black ills foresters have wondered whether it would e worthwhile to intensify control over stocking in ne managed ponderosa pine stands. Specifically, ney have questioned whether potential gains in rowth and yield would be adequate to justify the extra cultural effort and expense. Local research on thinning has not yet generated a satisfactory answer.

The purpose of this Note is to provide Black Hills foresters with a preliminary look at what they may be able to accomplish with a more aggressive, more imaginative use of the thinning "tool." The Note describes results of a small demonstration in which two thinnings, in rapid sequence, produced major changes in the structure and productivity of an immature ponderosa pine stand. Although the results are too limited in scope to support treatment prescriptions for operational use, they strongly suggest that intensified thinning may prove desirable and justifiable.

Stands and Treatments

The demonstration involved two plots, each with a gross area of about 0.4 acre, including isolation strips. Plots were installed in a typical stagnant, "doghair" stand of 70-year-old ponderosa pine saplings (fig. 1).

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[1] *Silviculturist, located at Rapid City, n cooperation with the South Dakota School of ines and Technology; central headquarters is aintained at Fort Collins, in cooperation ith Colorado State University.*

Figure 1.--Unthinned plot stand in 1968: 80 years old, about 2,000 trees and 200 square feet of basal area per acre, average d.b.h., 4.2 inches.

Quality of the plot site is above average for the Black Hills—site index is estimated to be 70 feet at 100 years. Soil is a well-developed, moderately deep, silt-loam, apparently derived in place from underlying limestone parent material. Plots are situated side by side on the lower third of a northeast-facing slope, where the average gradient is about 10 percent. The area normally receives about 20 inches of precipitation per year.

When established in the summer of 1957, one plot was stocked with the equivalent of 2,838 trees and 187 square feet of basal area per acre; average d.b.h. was 3.5 inches. The other plot was stocked with 1,976 trees and 191 square feet of basal area per acre; average d.b.h. was 4.2 inches. The latter plot was selected by chance to be thinned; the other was designated as a control and left unthinned.

The first thinning (T-1) was made near the end of the 1957 growing season. It conformed closely in character and intensity to precommercial thinnings being made routinely in similar stands throughout the Black Hills National Forest, then and now (fig. 2). Although best described as a moderately heavy cut from below, the thinning also removed some trees of poor quality or low vigor from the upper size and crown classes.

The intent was to leave about 80 square feet of basal area per acre—the reserve density recommended in National Forest Marking Guides for pole stands on sites of average quality. Because some leave trees were broken by snow the following spring, the stand contained only 71 square feet of basal area and 476 trees per acre at the beginning of the 1958 growing season. Leave trees were uniformly distributed over the plot at an average spacing of about 10 x 10 feet. Average spacing in the control stand was about 4 x 4.

By the end of the seventh (1964) growing season after the initial thinning, the majority of the trees in the thinned stand showed signs of a decline in diameter growth. To forestall that decline, the stand was thinned again before the start of the 1965 growing season (fig. 3).

This second thinning (T-2) was a radical departure from the customary approach to stocking control: it was made 10-15 years earlier than the usual rethinning, and it left a much lighter reserve stand. Stocking density before T-2 was 419 trees per acre, down slightly from the number left by T-1 because of additional losses from snowbreak. Basal area had increased from 71 to 98 square feet per acre. T-2 reduced stocking to only 105 trees, spaced about 20 feet apart, and 35 square feet of basal area.

Figure 2.--First thinning underway in treated plot, late summer of 1957: residual stand contained about 500 trees and 80 square feet of basal area per acre.

Figure 3.--Thinned stand 1 year after 1964 rethinning: contains about 100 8-inch trees per acre; rank ground cover of grass and forbs overtops lopped-and-scattered slash.

It left only the "cream" of the growing stock—trees of good quality that had shown the most vigorous response to release after T-1. Growth of these widely spaced leave trees was observed closely for four growing seasons following T-2, or through the end of the 11th growing season after T-1.

There was no effective change in stocking in the control stand during the same 11-year period. Natural thinning eliminated nearly 900 trees per acre, mostly in the suppressed and overtopped classes, but this reduction probably did little to relieve competition among the nearly 2,000 trees per acre that remained alive. Basal area density showed a net increase of 6 square feet per acre and totaled 193 square feet in the fall of 1968.

Periodic Growth

Diameter and Height

Average d.b.h. of the control stand increased by only 0.7 inch during the 11-year period (table 1). Part of this meager increase resulted from death of small trees; the remainder from growth of survivors. Growth of the largest 100 trees p acre increased their mean d.b.h. from 6.7 to 7 inches.

Concurrently, average tree height in the contr stand, based on sample trees from all d.b.h. classe increased by 8 feet. A major part of this increa is also attributable to death of small trees, sin average height growth of the tallest 100 trees p acre was only 4.1 feet.

In sharp contrast, the average d.b.h. of th thinned stand more than doubled between 19 and 1968. Removal of small trees in the two thi nings produced immediate increases totaling 2 inches. Accelerated growth of leave trees add another 2.6 inches. Thus, the aggregate 11-ye increase was 4.9 inches.

Trees left by T-1 grew at an average rate 0.2 inch per season for the seven growing seaso prior to T-2. That rate is about what one wou expect as a growth response to a typical precor mercial thinning in a typical doghair sapling sta on a good Black Hills site.

Far less predictable was the extra impetus i parted to d.b.h. growth by T-2. The widely spac trees left by that thinning promptly increased the average diameter increment to 0.3 inch in the fi

Table 1.--Characteristics of sequentially thinned and control stands, Black Hills ponderosa pine 1958-68 (acre-base)

Stand	Age	Trees	Average d.b.h.	Average height	Basal area	Total volume[1]	Merchantable volume[2]
	Years	No.	Inches	Feet	Sq. Ft.	Cu. Ft.	Cu. Ft.
THINNED:							
Before T-1	70	1976	4.2	32	191	2612	689
After T-1	70	476	5.2	36	71	1123	420
Before T-2	77	419	6.5	42	98	1637	1089
After T-2	77	105	7.8	44	34	628	545
After T-2	81	105	9.1	49	48	957	882
CONTROL:							
1958 (Apr.)	70	2838	3.5	29	187	2337	294
1968 (Oct.)	81	1992	4.2	37	193	2971	948

[1] All trees, full stem including stump and top.

[2] Trees larger than 5.9 inches d.b.h., excluding 1-foot stump and topwood less than 4.0 inches i.

jrowing season—a jump of 50 percent.[2] Furthernore, they maintained that high rate for each of he next three seasons. Such rapid diameter jrowth—equivalent to 3 inches per decade—has iot been reported previously for Black Hills ponlerosa pine.

By 1968, treatment had produced marked differences in structure, as well as average d.b.h. of the wo stands (fig. 4). Range of stem diameters in he thinned stand was less than 3 inches; range in he control stand was twice as wide. Distributions overlapped only slightly in the 8-inch d.b.h. class.

Thinnings also produced dramatic changes in average tree height and height increment. T-1 removed enough small trees to provide an immediate 4-foot increase in average total height. Seven years of growth prior to T-2 added another 6 feet. T-2 produced a 2-foot gain and 5 feet more were added by growth during the final period. Altogether, then, average height of thinned trees was increased by 17 feet in only 11 years.

Basal Area and Volume

One key question remains: Did the drastic, stepwise reduction in stocking in the thinned stand adversely affect basal area and volume growth? Table 1 shows the large fluctuation in basal area caused by thinnings and subsequent growth in the treated stand, and the small net increase in basal area in the control stand. More important, however, is the comparison between rates of basal area increment following the two thinnings. Average annual rate for the 7 years after T-1 was 3.9 square feet per acre. Average annual rate for the 4 years after T-2 was 3.5 square feet per acre. Thus, the seemingly drastic second thinning—which removed 75 percent of the trees and 65 percent of the basal area—reduced basal area increment by only 10 percent.

What about growing stock volume and volume growth? In the control stand, total volume increased from 2,337 to 2,971 cubic feet per acre in 11 years, at an average annual rate of 58 cubic feet. At first glance, this might seem a disproportionately large volume increment for a stand that lost nearly 900 trees to mortality and showed a net basal area increase of only 6 square feet per acre. The explanation is that, while average tree diameter increased by only 0.7 inch, average tree height increased by about 8 feet—the combined result of slow but steady growth, and death of many small trees. Evidently, then, the substantial volume increment was primarily a function of increasing stand height, with basal area increment making only a minor contribution.

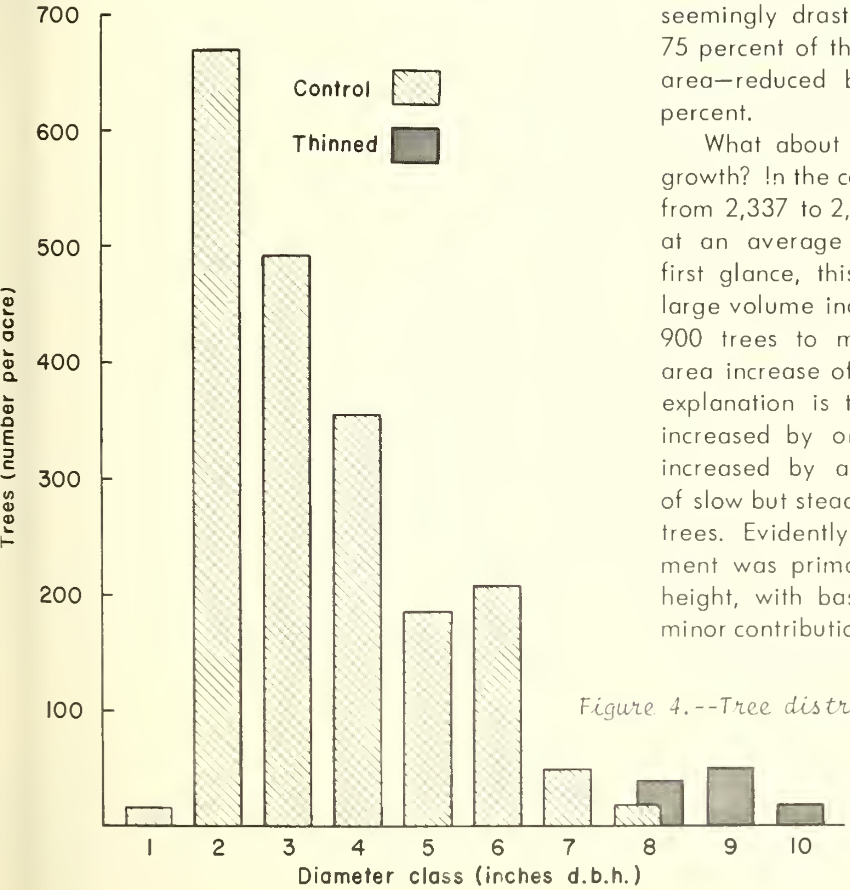

Figure 4.--Tree distribution by 1-inch d.b.h. classes in sequentially thinned and control stands, end of 1968 growing season.

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[2] Some part of this increase may be attributable to a basal shift in the zone of naximum diameter increment within stems. Such a shift is known to have occurred in some trees left by T-1 (Van Deusen, James L. Periodic growth of pole-sized ponderosa pine as related to thinning and selected environmental factors. U.S.D.A. Forest Serv. Res. Pap. RM-38. 12 p., illus. 1968. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.) Form changes in T-2 reserve trees are being evaluated and will be reported later.

In the thinned stand, volume growth averaged 73 cubic feet per acre per year for the 7 years following T-1; total growing stock volume increased from 1,123 to 1,637 cubic feet. Although T-2 removed slightly more than 1,000 cubic feet and left only 628, volume production increased to an average of 82 cubic feet per year for the next four growing seasons.

During the final season of record, 1968, the stand added 97 cubic feet of wood per acre on an initial growing stock volume of only 860 cubic feet. That is equivalent to a simple interest return on wood "capital" of more than 11 percent. It is also notable that T-2 produced no depression in volume increment, even though basal area growth was slightly reduced. As in the control stand, tree height was evidently increasing rapidly enough to compensate for the small drop in basal area growth.

Because merchantability is primarily a function of stem diameter, thinning had a more profound influence on merchantable volume production tha on total volume production (fig. 5). During the years between the two thinnings, the thinned stan added merchantable volume at an average annu rate of 96 cubic feet or 1.25 cords per acre. Seen ingly, merchantable volume was being generate faster than total volume. Actually, however, th excess was the result of steady recruitment of tree into the merchantable class, comprised of tree larger than 5.9 inches d.b.h.

Yield of merchantable roundwood from th second thinning was equivalent to 7.0 cords pe acre, or about 80 percent of the merchantabl volume accumulated after T-1. Because T-2 le no trees smaller than 6.0 inches d.b.h., averag yearly increment in merchantable volume was equ to total volume increment—82 cubic feet or 1 cords per acre for the 4-year period, and 97 cub feet or 1.26 cords for the 1968 growing seaso

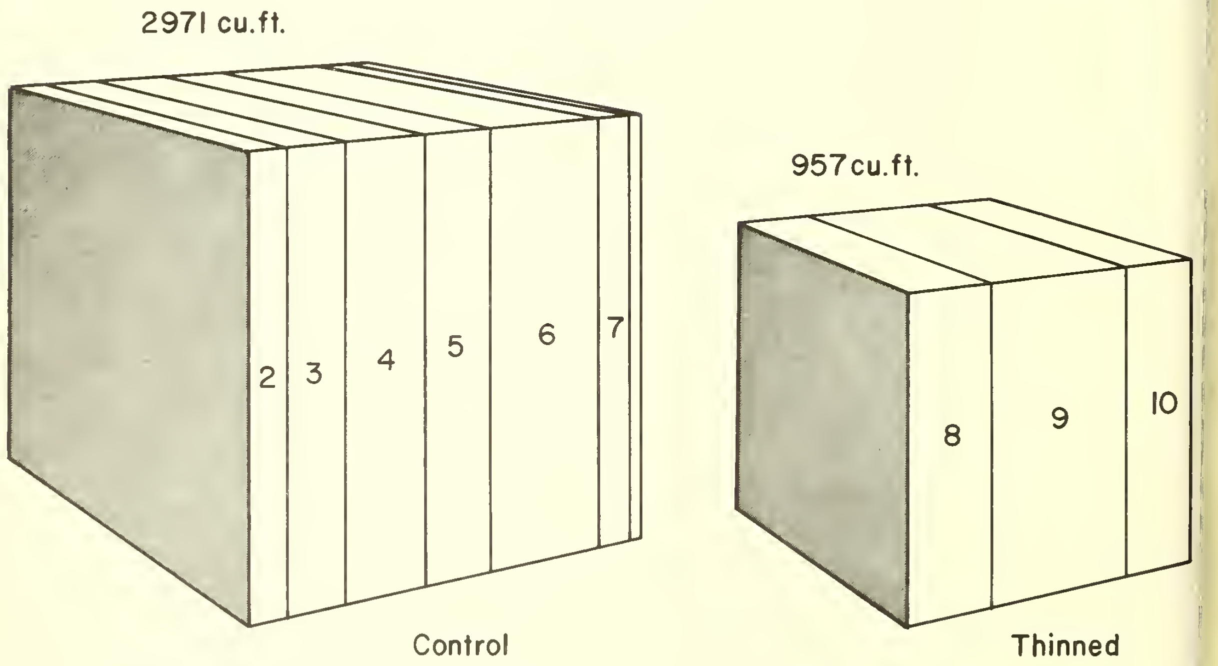

Figure 5.--Proportional distribution of total cubic foot volume (per acre) by 1-inch d.b.h. classes, sequentially thinned and control stands, end of 1968 growing season.

There is another important aspect of merchant- ble growth in the thinned stand. In 1969, at the art of the fifth growing season after T-2, that stand egan accumulating board foot volume, since its verage stem diameter exceeded the 9.0-inch reshold d.b.h. Inception of board foot production nly 11 years after a first precommercial thinning a sapling stand is perhaps the most provocative sult of the demonstration.

Merchantable volume increment in the control and was surprisingly high. It averaged 59 cubic et or 0.76 cord per acre per year. The unex- ected equality between merchantable and total olume growth in the control stand can only be xplained as the result of the same process that used merchantable increment to exceed total in- ement in the thinned stand—ingrowth into the erchantable diameter class.

In terms of 11-year totals, the control stand dded 8.5 cords of merchantable wood per acre nd had a final volume of 12.3 cords. During e same period the thinned stand added 13.1 rds, yielded an intermediate harvest of 7.0 cords, et still contained 11.5 cords in the standing crop the end of the period.

Interpretation

For the full impact of what the sequential thin- ing accomplished, assume that the same doghair apling stand was thinned according to current anagement practices. After two moderate thin- ings, 20 years apart, the stand could be expected reach the threshold of the saw-timber size class 30 to 35 years. When stimulated by sequential inning, the stand advanced to the same threshold only 11 years.[3]

The rationale of treatment success is clearly vident. Because of the special way the two thin- ngs were related—in time, character, and severity— ach complemented and enhanced the benefits of e other. In effect, they were component steps a single intensive silvicultural treatment.

The conventional first thinning was basically a preparatory cut. Its moderate severity was a compromise between the urgent need to open the stand and the risk of opening it too much, too fast. It eliminated most of the least promising trees, yet left enough to provide a hedge against losses to windthrow, snowbreak, and insects. It reduced competition sufficiently to elicit a prompt and substantial improvement in growth and vigor of the more aggressive reserve trees.

The second thinning was both timely and rigorous. It was made while most of the trees were still actively responding to the release provided by T-1. It left only robust trees with a proven capacity for rapid growth. Finally, it left each of these top-quality trees with what was roughly estimated to be the maximum amount of growing space that it could effectively utilize. The strategy was to reduce stand density to the verge of incomplete site occupancy, and thus give each leave tree the chance to achieve its full growth potential. Evidently, that critical level of stocking was approached closely by the T-2 reserve stand.

Although the growth responses of trees left by T-2 were good, by Black Hills standards, it seems probable that the potential for trees of this size may be even greater. These trees were relatively old when first released, and their growth and development had been severely retarded for several decades. Younger trees of similar size, with larger and more vigorous crowns and root systems, might be expected to perform substantially better under equivalent site and stand conditions.

Finally, what can be inferred about applicability of sequential thinning to other Black Hills stands and sites? Certainly, the underlying principles of timely rethinning and adequate release of the best available growing stock are silviculturally sound and applicable wherever even-aged stands are managed. Beyond that, however, it is impossible to translate the results of a one-plot demonstration into any defensible generalizations of the sort that are operationally useful—that is, reliable thinning prescriptions and devices for predicting treatment results. Such refined management tools will be forthcoming, however, from comprehensive studies now underway.

In the interim, demonstration findings brighten the prospects for major gains in productivity of Black Hills pine forests—through more intensive silviculture.

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[3] *Myers, Clifford A. Yield tables for man- ged stands with special reference to the Black lls. U. S. Forest Serv. Res. Pap. RM-21, p., illus. 1966. Rocky Mt. Forest and nge Exp. Sta., Fort Collins, Colo.*

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U S D A FOREST SERVICE
RESEARCH NOTE RM 173

ST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fourwing Saltbush Can Be Field Planted Successfully[1]

Earl F. Aldon[2]

Fourwing saltbush, Atriplex canescens (Pursh) Nutt., survived well and grew more than 1 foot during the first year when native seed was grown to 4- to 6-week-old transplants, then transferred to low sites that received some flooding before planting.

KEY WORDS: Atriplex canescens, plant propagation, transplanting, soil stabilization.

Fourwing saltbush, Atriplex canescens (Pursh) Nutt., a nutritious, all-season forage plant for domestic livestock, also provides excellent food and cover for wildlife species.

This Note reports several methods tested during 1968 and 1969 to field plant transplants[3] for maximum survival and height growth.

Planting sites were in silty clay soil on alluvial lood plains behind newly constructed flood-detention structures on the Rio Puerco in New Mexico, where he Bureau of Land Management wanted to use ourwing saltbush to trap sediment and provide ood and cover for quail.

Transplants, 4 to 6 weeks old, were field planted n July. All sites were treated with straw mulch and animal repellent immediately after the seedings were planted.

To determine soil moisture on each planting date, one 1-inch-core soil sample was taken at the bottom of each of 10 randomly selected planting holes at each site.

Seed used to grow the transplants came from wo sources. One source, called Camp 8, was saltbush plants growing within 5 miles of the planting site; the second source was a commercial firm that had collected its seeds near Las Cruces, New Mexico, called Las Cruces.

Survival was recorded in percent, then transformed to arc sin for analysis. The 5 percent level of probability was accepted for significance in all analyses.

1968 Planting

Transplants from both seed sources were planted at three sites, and at two depths, in a split-split-plot experimental design. Some seedlings were transplanted before the sites received enough rain to cause flooding; others, after the sites were flooded.

The two planting depths tested were (1) shallow, when the tops of the 3-inch plant bands were placed even with the soil surface; and (2) deep, when the bands were placed below the soil surface so that soil covered about half of the plant stem.

Survival of living plants and height growth were recorded (1) immediately after planting, (2) at the end of the first growing season, and (3) 1 year after planting.

Practically no transplants survived on the sites that were planted before flooding. Soil moisture was well below wilting point at planting time—6.0 percent by weight. Apparently, some initial soil moisture is necessary for transplants to survive the intense sunlight, high temperatures, and drying winds common to the Southwest prior to summer thunderstorms.

On the sites planted after flooding, soil moisture averaged 19.1 percent by weight, which is about one-third atmosphere for these soils.

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[1] *Study conducted in cooperation with Bureau of Land Management, U. S. Department of the Interior, Albuquerque, New Mexico.*

[2] *Principal Hydrologist, located at Albuquerque, in cooperation with the University of New Mexico; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

[3] *Techniques and recommendations are reported in: Aldon, Earl F. Growing fourwing saltbush transplants for field planting. USDA Forest Serv. Res. Note RM-166, 3 p., illus. 970. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.*

Transplants, 4 to 6 weeks old, grown from local seed (Camp 8) and shallow planted on a flooded site, survived better and grew taller than all other combinations (table 1).

Local seed outperformed other seed by 17 percent and shallow planting had a 7 percent increase over deep planting in 1969 survival results (table 1). These results were inconsistent by site, due to unknown reasons, so that significance at the desired level was not demonstrated.

Height growth, as expected, was negligible at the end of the first growing season. Camp 8 seed showed a real average height increase of 0.69 foot per plant over Las Cruces seed by the end of the first year. Contrary to survival data, site did not affect height growth; the surviving plants grew equally well on all sites.

1969 Planting

All 1969 sites were planted after one flooding because of the 1968 failure on the dry sites. Two 1968 sites were replanted, and two new sites were selected. Transplants from Camp 8 seed were used because of the superior results obtained in 1968.

Four planting treatments, in a randomized block test, gave the following results at the end of one growing season (October 1969):

Treatment	Survival (percent)
1. Check. Plant bands shallow planted as in 1968	60
2. Hole dug, water placed in bottom of hole, transplant shallow planted	58
3. Transplant and its plant band submerged in water for 2 hours; water drained, transplant and band shallow planted as in check[4]	70
4. Depression dug; transplant planted in bottom	27

Overall survival was lower in 1969 than 1968, possibly because soil moisture at planting time averaged only 13 percent by weight. More transplants survived under treatment 3, although treatments 1, 2, and 3 did not differ significantly from each other. Survival under treatment 4 was significantly lower, however, where silt filled the depression, and the area resembled the 1968 deep-planted trials.

Recommendations

Preliminary conclusions drawn from this limited study indicate that fourwing saltbush can be planted and grown most successfully by:

1. Growing transplants from native seed (seed collected from plants growing near the area to be replanted). Ecologically, this is an accelerated method of getting native plants to reinvade devastated areas.
2. Field planting 4- to 6-week-old transplants that have been grown by certain techniques.[3]
3. Field planting with plant bands at ground level, not in depressions.
4. Field planting in low areas that will receive some flood waters, but water will not submerge the new transplants for longer that 30 hours.[4]
5. Field planting soon after the area has been flooded to insure some available soil moisture, since transplants did not survive well on dry sites.

Table 1.--Condition of fourwing saltbush transplants on three sites planted after flooding, July 1968

Seed source	Planting depth	Average survival: End of first growing season (October 1968)	Average survival: 1 year after planting (July 1969)	Height growth 1 year after planting (July 1969)
		Percent		Feet
Camp 8	Shallow	100	83	1.12
	Deep	80	47	.91
Las Cruces	Shallow	77	66	.44
	Deep	60	37	.23

[1] Analyzed by deleting dead plants, then using a disproportionate analysis.

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[4] *Results obtained from another study are reported in: Aldon, Earl F. Fourwing saltbush survival after inundation. USDA Forest Serv. Res. Note RM-165, 2 p. 1970. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.*

Agriculture --- CSU, Ft. Collins

U S D A FOREST SERVICE
RESEARCH NOTE RM- 174

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Sequential Plan for Western Budworm Egg Mass Surveys in the Central and Southern Rocky Mountains

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A sequential plan is presented for sampling the western budworm (Choristoneura occidentalis Freeman) on Douglas-fir in the central and southern Rocky Mountains. Infestations are classified according to numbers of new egg masses per 24-inch branch corresponding to defoliation expected the succeeding season. The plan is designed for use in well-defined entomological units of forest area limited in size by infestation history and management objectives.

KEY WORDS: Sample designs (forestry), forest insects, Choristoneura occidentalis, Pseudotsuga menziesii.

Forecasts of defoliation by the western budworm horistoneura occidentalis Freeman) are usually sed on densities of new egg masses determined survey (Carolin and Coulter 1959). The sequenl sampling plan described here is more flexible, d usually more efficient, than the procedure w used.

Sequential sampling plans are used widely in rest insect surveys. Very low or very high poputlon levels can be classified with a minimum numr of samples, usually fewer than if a scheme with a fixed number of samples were used. When population levels are intermediate, the sampling job may be larger than with a fixed number of samples.

The sequential plan presented here is designed for use in well-defined entomological units whose boundaries are related to management objectives, past and current defoliation conditions, or planned suppression programs. If the unit is small, the survey may be too expensive to be justified except in high-value stands. If the unit is too large, defoliation predictions will be generalized and local conditions may differ considerably from predicted intensities. Also, the manpower and travel to distribute the samples adequately will be excessive.

This sequential plan is intended for sampling budworm populations on Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) in the central and southern Rocky Mountains. We do not have evidence that it can be used on other host species without adjustments for differences in population-damage relationships.

The Sequential Plan

In this plan, we use numbers of new egg masses per 24-inch branch to classify budworm infestations into one of four classes. These classes correspond

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to degrees of defoliation to be expected. Our earlier investigations indicated that the density of new egg masses can be estimated as well with 24-inch branches as with half-branches (McKnight 1968). The areas of 24-inch branches are usually about 250 square inches; therefore, the number of egg masses per 24-inch branch is easily converted to conventional expressions of egg mass density per 1,000 square inches of foliage.

New egg masses were counted on ten 24-inch branches from each of 38 plots in southern Colorado. Data were tested graphically and appeared to conform to the negative binomial distribution. A pooled constant k = 5.106, the characteristic parameter of the negative binomial, was computed by the method of Bliss and Owen reported by Waters (1955). Users of this plan should be aware that the parameter k may be different for budworm populations in other areas.

The class limits for the four classes of infestation (table 1) were derived from data relating densities of new egg masses to subsequent defoliation.[4] These data were gathered between 1959 and 1966 from budworm infestations on Douglas-fir in New Mexico and Colorado. Half-branch samples were used to obtain estimates of new egg mass density per 1,000 square inches; defoliation was estimate with field glasses or by examining shoots.

The risks of error specified in the plan represen compromises between precision of estimation an reasonable numbers of samples. For differentiatin between infestations of classes 1 and 2, the ris of being wrong is four times in 10 ($\alpha = \beta = 0.40$); between classes 2 and 3, the risk of being wrong i one time in 10 ($\alpha = \beta = 0.10$); and between classe 3 and 4, the risk is two times in 10 ($\alpha = \beta = 0.20$

Decision lines were computed for each class t be distinguished. Waters (1955) and others presente the equations for the decision lines for the negativ binomial distribution. The computed k, the clas limits (table 1), and the risks of error stated abov were used in the equations to compute the sequential table (table 2).

A minimum of 50 samples, two branches from each of 25 trees, must be taken from each entomological unit. The average number of sample required to classify each infestation will depen largely on the population level. The greates number of samples will be necessary in borderlin cases between classes. The sequential table wa computed for 300 samples, which should be sufficient to classify most units.

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[4] *McKnight, M. E. Report on analysis of budworm data. Unpublished report on file at the Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo. 11 p. 1968.*

[5] *α = risk of rejecting the hypothesis when it is true.*
β = risk of accepting the hypothesis when it is false.

Table 1.--Class limits for the sequential sampling plan for western budworm egg mass surveys

Class	New egg masses per 24-inch branch	equals	New egg masses per 1,000 square inches	Defoliation prediction[1]
		Number		
1	0.250 or fewer		1.0 or fewer	undetectable
2	0.275 to 1.0		1.1 to 4.0	undetectable in "static" infestations, light in "increasing" infestations
3	1.5 to 5.0		6.0 to 20.0	light in "static" infestations, moderat in "increasing" infestations
4	5.5 or more		22.0 or more	moderate or heavy

[1] Percent defoliation of current growth:

undetectable =	0 to 5
light =	5 to 35
moderate =	35 to 65
heavy =	65 and over

Using the Sequential Plan

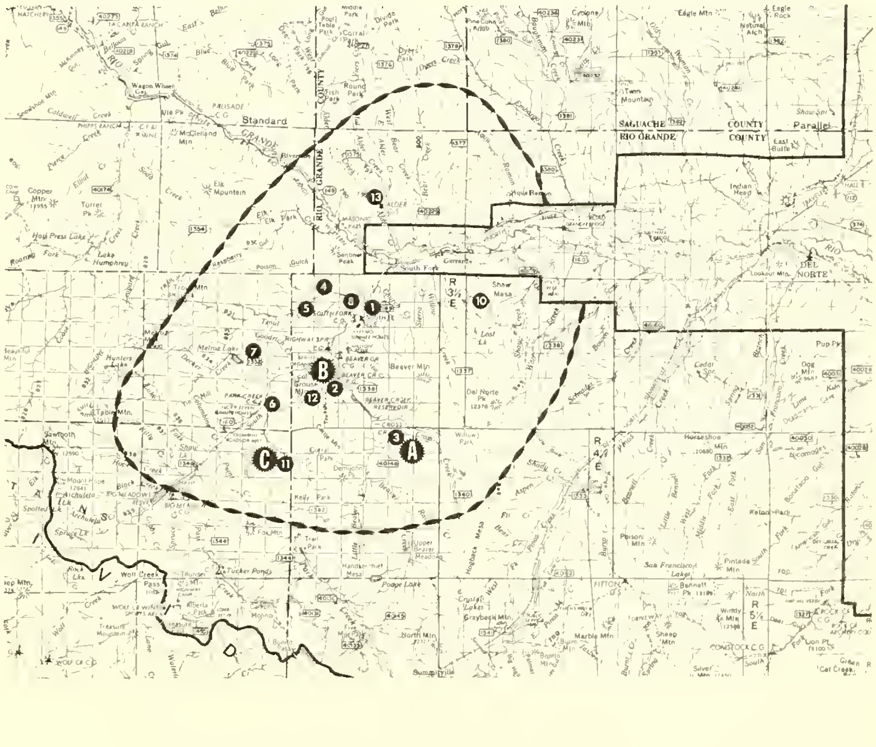
Use of the sequential plan will vary considerably, t the principal problem will be to obtain samples om representative parts of the entomological unit. all parts are easily accessible, the unit should be 'dded into a large number of subunits consecutively mbered; section-sized subunits would be appro- iate for U. S. Forest Service maps. At least 25 bunits should be drawn at random; each of the subunits should be visited and two branches ken from one tree in each. If a unit is largely accessible, the sequential plan can be used for mpling one or two trees at intervals along roads trails in the entomological unit (fig. 1).

The field crews should use uniform collection ethods. They should choose codominant Douglas- s, usually 50 to 70 feet tall, not top killed nor verely defoliated, for sampling. Cut from each lected tree two branches, each at least 24 inches ng, from the midcrown, with a pole pruner (fig. 2). basket can be attached to the pruner to catch the t branch, or a holding device (Stein 1969) can installed on the pruner head to hold the cut anch as it is lowered to the ground or to a drop th. Discard branches which fall down through e crown and brush several branches. The outline the foliage should be about 25 inches long and 20 inches wide to give an area (figured as a triangle) of 250 square inches. Branches that are too large can be reduced in length only (fig. 3); do not clip foliage from the periphery of the branch. Discard branches that are too small, and take replacements from the same tree.

Cut branches can be conveniently handled in 1/4-bushel paper bags, 27 by 16 by 6 inches. Both 24-inch branches from a sample tree can be placed in the same sack without any additional clipping (fig. 4). Sacks are easily bundled together with a large rubber band cut from an inner tube (fig. 5). The foliage transports well and is easily stored in paper sacks.

In the laboratory, examine the foliage from 50 branches for egg masses. Count only the new egg masses, laid in the year of the survey. New egg masses are erect, transparent, and shiny; old egg masses are, to varying degrees, collapsed, opaque, and dull (Buffam and Carolin 1966).

Consult the sequential table (table 2) to determine if the infestation can be classified immediately, or if more branches must be examined. For example, if 50 branches were examined and 131 new egg masses were counted, the entomological unit is called class 3 with light or moderate defoliation expected. If 240 new egg masses were found, more samples must be examined until the number of egg masses falls within the limits for class 3



ure 1.--An entomological nit on the Rio Grande lational Forest established n the basis of history of udworm infestations.

Table 2.--Sequential table for sampling egg masses of the western budworm on 24-inch branches

Number of 24-inch branches examined	Infestation class										
	1		2				3				4
	- - - Number of new egg masses - - -										
50	[1] 9	Continue sampling	18	to	55	Continue sampling	68	to	233	Continue sampling	[2] 292
52	9		18		57		71		243		302
54	10		19		60		73		254		313
56	10		19		62		76		264		323
58	11		20		65		78		275		334
60	11		20		67		81		285		344
62	12		21		69		83		296		355
64	12		21		72		85		306		365
66	13		22		74		88		317		376
68	13		22		77		90		327		386
70	14		23		79		93		338		396
72	14		23		82		95		348		407
74	15		24		84		98		359		417
76	15		24		87		100		369		428
78	16		25		89		103		380		438
80	16		25		92		105		390		449
82	17		26		94		108		401		459
84	18		26		97		110		411		470
86	18		27		99		112		421		480
88	19		27		101		115		432		491
90	19		28		104		117		442		501
92	20		29		106		120		453		512
94	20		29		109		122		463		522
96	21		30		111		125		474		533
98	21		30		114		127		484		543
100	22		31		116		130		495		554
172	[1] 41	Continue sampling	49	to	205	Continue sampling	218	to	872	Continue sampling	[2] 931
174	41		50		207		221		883		942
176	42		51		210		223		893		952
178	42		51		212		226		904		963
180	43		52		215		228		914		973
182	43		52		217		231		925		984
184	44		53		220		233		935		994
186	44		53		222		235		946		1005
188	45		54		224		238		956		1015
190	45		54		227		240		967		1026
192	46		55		229		243		977		1036
194	46		55		232		245		988		1047
196	47		56		234		248		998		1057
198	47		56		237		250		1009		1068
200	48		57		239		253		1019		1078
202	48		57		242		255		1030		1089
204	49		58		244		258		1040		1099
206	49		58		247		260		1051		1110
208	50		59		249		263		1061		1120
210	51		59		252		265		1072		1131
212	51		60		254		267		1082		1141
214	52		60		256		270		1093		1152
216	52		61		259		272		1103		1162
218	53		62		261		275		1114		1173
220	53		62		264		277		1124		1183
222	54		63		266		280		1135		1194
224	54		63		269		282		1145		1204
226	55		64		271		285		1156		1215
228	55		64		274		287		1166		1225
230	56		65		276		290		1177		1236

102	22	31	119	132	505	564	232	56	65	279	292	1187	1246
104	23	32	121	135	516	575	234	57	66	281	295	1198	1256
106	23	32	124	137	526	585	236	57	66	283	297	1208	1267
108	24	33	126	140	537	596	238	58	67	286	299	1219	1277
110	24	33	129	142	547	606	240	58	67	288	302	1229	1288
112	25	34	131	144	558	617	242	59	68	291	304	1240	1298
114	25	34	133	147	568	627	244	59	68	293	307	1250	1309
116	26	35	136	149	579	638	246	60	69	296	309	1261	1319
118	26	35	138	152	589	648	248	60	69	298	312	1271	1330
120	27	36	141	154	600	659	250	61	70	301	314	1282	1340
122	27	36	143	157	610	669	252	62	70	303	317	1292	1351
124	28	37	146	159	621	680	254	62	71	306	319	1302	1361
126	29	37	148	162	631	690	256	63	71	308	322	1313	1372
128	29	38	151	164	642	701	258	63	72	311	324	1323	1382
130	30	38	153	167	652	711	260	64	73	313	327	1334	1393
132	30	39	156	169	663	722	262	64	73	315	329	1344	1403
134	31	40	158	172	673	732	264	65	74	318	331	1355	1414
136	31	40	160	174	684	743	266	65	74	320	334	1365	1424
138	32	41	163	176	694	753	268	66	75	323	336	1376	1435
140	32	41	165	179	705	764	270	66	75	325	339	1386	1445
142	33	42	168	181	715	774	272	67	76	328	341	1397	1456
144	33	42	170	184	726	785	274	67	76	330	344	1407	1466
146	34	43	173	186	736	795	276	68	77	333	346	1418	1477
148	34	43	175	189	747	806	278	68	77	335	349	1428	1487
150	35	44	178	191	757	816	280	69	78	338	351	1439	1498
152	35	44	180	194	768	826	282	69	78	340	354	1449	1508
154	36	45	183	196	778	837	284	70	79	343	356	1460	1519
156	36	45	185	199	789	847	286	70	79	345	358	1470	1529
158	37	46	188	201	799	858	288	71	80	347	361	1481	1540
160	37	46	190	204	810	868	290	71	80	350	363	1491	1550
162	38	47	192	206	820	879	292	72	81	352	366	1502	1561
164	38	47	195	208	831	889	294	73	81	355	368	1512	1571
166	39	48	197	211	841	900	296	73	82	357	371	1523	1582
168	40	48	200	213	851	910	298	74	82	360	373	1533	1592
170	40	49	202	216	862	921	300	74	83	362	376	1544	1603

1/ or fewer

2/ or more

Figure 2.--A 24-inch branch is cut from midcrown.

or class 4. If the same entomological unit (not necessarily the same subunits) was sampled the previous year and placed in class 2, the trend is upward.

Only one pair of infestation classes can be differentiated in any one survey. The possible pairs are: class 1, or class 2 or higher; class 2 or lower, or class 3 or higher; class 3 or lower, or class 4. A new set of samples must be taken for each pair of decision lines used.

Figure 3.--Length of cut branch is reduced to 24 inches.

It may not be necessary to identify the infestation class exactly in every survey. For example the objective of the survey may be to decide whether or not an infestation is greater than class 3 if the resource manager has decided to carry out suppression when populations reach class 4 For high-value crops such as Christmas trees, suppression may be justified if populations are determined to be of class 2 or higher, or perhaps class 1. The objective of the survey would then be to differentiate between class 1 and class 2 or higher.

The survey should be planned to avoid repeated sampling trips. Two trees could be sampled in each subunit at the first visit. The foliage from one tree in each subunit would be examined first. If more samples were needed, the foliage from the second tree in each subunit could then be examined.

Experience with the sequential sampling plan may show that current defoliation, recorded in the aerial survey or at the time of foliage collection, is an index of the number of trees to be sampled to avoid repeated visits. Current defoliation in the entomological unit can be estimated during the egg mass survey with little extra effort. One hundred new shoots are selected at random from the foliage collected for egg mass counts, and the shoots undamaged by feeding by budworm larvae are tallied. The defoliation estimate is read from table 3, which relates the percent undamaged shoots to percent defoliation (McKnight 1969).

Both branches from each sample tree are carried in the same paper sack without clipping.

Figure 5.--Paper sacks with foliage are easily transported and stored.

Table 3.--Estimation of percent defoliation of current growth on Douglas-fir and white fir from counts of undamaged shoots

nt ged s	Percent defoliation		Percent undamaged shoots	Percent defoliation		Percent undamaged shoots	Percent defoliation		Percent undamaged shoots	Percent defoliation	
	Douglas-fir	White fir		Douglas-fir	White fir		Douglas-fir	White fir		Douglas-fir	White fir
0	89	76									
1	87	75	26	51	41	51	25	18	76	8	4
2	86	73	27	50	40	52	24	17	77	7	4
3	84	72	28	49	39	53	23	17	78	7	4
4	82	70	29	47	38	54	22	16	79	6	3
5	81	69	30	46	37	55	21	15	80	6	3
6	79	67	31	45	36	56	21	14	81	5	3
7	78	66	32	44	35	57	20	14	82	5	3
8	76	64	33	43	34	58	19	13	83	5	2
9	75	63	34	42	33	59	18	13	84	4	2
0	73	62	35	41	32	60	17	12	85	4	2
1	72	60	36	39	31	61	17	11	86	4	2
2	70	59	37	38	30	62	16	11	87	3	2
3	69	58	38	37	29	63	15	10	88	3	1
4	67	56	39	36	28	64	15	10	89	3	1
5	66	55	40	35	27	65	14	9	90	2	1
6	64	54	41	34	26	66	13	9	91	2	1
7	63	52	42	33	25	67	13	8	92	2	1
8	62	51	43	32	24	68	12	8	93	2	1
9	60	50	44	31	24	69	11	7	94	1	1
0	59	49	45	30	23	70	11	7	95	1	1
1	58	47	46	29	22	71	10	6	96	1	1
2	56	46	47	28	21	72	10	6	97	1	1
3	55	45	48	27	20	73	9	6	98	1	1
4	54	44	49	26	20	74	9	5	99	0	1
5	52	43	50	26	19	75	8	5	100	0	1

Operational Efficiency

The sequential plan was used operationally in Forest Service Region 2 (Colorado) and Region 3 (New Mexico and Arizona) in 1968. Although budworm population levels were dissimilar, sampling efficiency was increased in both Regions.

In Colorado, 23 entomological units were established on seven National Forests. Each unit was characterized by one or more of the following factors: (1) large drainage with at least nearly continuous host material; (2) sufficient size for an effective aerial spray program; (3) history of budworm activity. The 23 units averaged 66,350 acres each.

Defoliation delineated in the aerial survey averaged 13,175 acres on 13 units; defoliation was not mapped on 10 units. In the egg mass survey, the 23 units were classified with an average of 53.2 samples per unit; 16 units were classified with 50 samples.

Survey personnel in Region 2 estimated that costs of foliage examination were reduced 70 percent by using 24-inch branches and the sequential sampling plan, and overall survey costs were reduced about 20 percent. Eliminating tree climbing for half-branch samples was an important added safety benefit.

In New Mexico and Arizona, nine entomological units, averaging 131,555 acres each, were established on the basis of past defoliation conditions and suppression programs. Defoliation delineated on two of the units totaled 111,000 acres; no defoliation was recorded on the other seven units. In the egg mass survey, eight units were classified with 50 branches each; one unit required 160 branches.

Survey personnel in Region 3 found the costs for foliage examination to be greatly reduced from that of previous years when half branches were used. In 1967, the foliage on half branches from 115 trees required 4.9 hours per tree for examination. In 1968, the foliage on 24-inch branch from 302 trees required 0.85 hour per tree f examination, a reduction in laboratory labor cos per tree of about 80 percent. The costs of folia collection were slightly reduced, and flexibility ar mobility of field crews was greater.

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Distribution of Dwarf Mistletoe in Ponderosa Pine Stands on the Beaver Creek Watershed, Arizona

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In cutover ponderosa pine stands on the Beaver Creek Watershed, frequency of dwarf mistletoe infection was highest on upper slopes and on areas of intermediate site index. Frequency was not related to aspect, slope steepness, or tree diameter.

KEY WORDS: Arceuthobium, Pinus ponderosa, site index.

Damage caused by dwarf mistletoes (Arceutho- um spp.) has become more important than heart ts in western coniferous forests. As the harvesting old stands continues, heart rot losses diminish ecause these losses are typically associated with ermature stands. Control of dwarf mistletoe in ung-growth stands has become the most pressing sue in forest pathology in the West.

Knowledge of dwarf mistletoe distribution in ands of ponderosa pine (Pinus ponderosa Laws.) uld be a useful tool for forest managers pre- ribing precommercial thinning, or pulpwood or nber sales, particularly in areas of heavy infesta- on in the Southwest.

Several factors have been reported to influence the distribution of mistletoe infection. Stand history is probably the most important, because the parasite is greatly reduced by severe fires or by heavy logging, and the return of trees into these areas is usually much faster than the invasion of dwarf mistletoe (Hawksworth 1961a). Hawksworth (1968) found that the frequency of dwarf mistletoe-infected trees was least on the poorest soils and intermediate on the best quality sites on the Manitou Experimental Forest, Colorado. Several studies in the Southwest (Andrews and Daniels 1960; Hawksworth 1959, 1961b) reported mistletoe frequency was highest on ridges, intermediate on slopes, and lowest on bottoms. The incidence of mistletoe was higher on moderate or gentle slopes than on steep slopes.

The observations presented in this Note describe the distribution of southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum (Engelm.) Hawks. and Wiens) on the Beaver Creek Watershed (Worley 1965) as related to aspect, slope position, slope steepness, site index, soil, and tree diameter.

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Location and Methods

The Beaver Creek Watershed is located within the Coconino National Forest, approximately 40 miles southeast of Flagstaff. Observations were made on nine ponderosa pine watersheds, totaling approximately 6,600 acres. About 85 percent of the overstory is ponderosa pine, and 15 percent is associated woodland species.

The pilot watersheds were cutover 15 to 20 years previously, leaving an uneven-aged residual stand that now averages 110 square feet basal area and 2,055 cubic feet volume per acre.

Data from 1,412 overstory inventory points were used to describe the occurrence of dwarf mistletoe. Trees greater than 7 inches d.b.h. intercepted by a 25 basal area factor (BAF) angle gage rotated about each point were tallied by 2-inch diameter classes, and checked for mistletoe. Trees were considered infected if a shoot of the parasite could be seen anywhere in the branches or bole (fig. 1). No attempt was made to quantify the degree of infection.

All Beaver Creek inventory points were classified by aspect (recorded as warm for SE, S, SW, and W, or cool for NW, N, NE, and E), slope position (recorded as upper 1/6, intermediate 2/3, or lower 1/6), and slope steepness (recorded as 0-7 percent, 8-17 percent, or 18 percent and greater).

Two soil management groups, Siesta-Sponseller and Brolliar, occur on the watersheds (Williams and Anderson 1967). The Siesta-Sponseller soil gr
which is derived from volcanic cinders and ba
is more productive than the Brolliar group w
is derived from basalt. Soils were described c
subsample of 571 points. Site indexes, grou
into Site Classes based on local Forest Ser
practices,[2] were determined on 726 points.

Data were analyzed on an inventory point b
for aspect, slope position, slope steepness, soil gr
and site class. A point was considered infe
with dwarf mistletoe if an infected tree was ta
at a point. However, to evaluate the distribu
of the parasite with respect to tree diameter,
proportion of infected trees within each 2-inch
meter class was determined. Chi-square anal
($\alpha = 0.05$) were used to study the relation of
quency of mistletoe infection to topographic cl
fications and to size classes.

Figure 1.--A pine branch infected with southwestern dwarf mistletoe.

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[2] Site Class I is equivalent to Mey
(1961) site 68 or better; Class II is eq
alent to site 53 to 67; and Class III is eq
alent to site 52 or less. Site index was
puted from a base age of 100 years.

Results and Discussion

Frequency of dwarf mistletoe infection varied ignificantly by site classes. The parasite occurred nost frequently on Site Class II and least on Site lass I, but was intermediate on Site Class III (fig.). There was also a significantly higher frequency f the parasite on the Siesta-Sponseller soil group han on the Brolliar soil group (fig. 2).

Several authors (Andrews and Daniels 1960; lawksworth 1959, 1961a, 1961b, 1967) report that warf mistletoe has an affinity for upper slope posiions and ridges. On the Beaver Creek Watershed, requency of mistletoe infection was higher on the pper slope position than on the intermediate and ower positions. No significant differences in freuency of mistletoe infection were found for the ther two topographical classifications (aspect and lope steepness).

The differences in mistletoe frequency among ite classes, soil groups, and slope positions were ot large, although statistically significant. Forest anagers should consider the practical importance of these differences when developing cutting guides or making silvicultural decisions. As an example, the differences in mistletoe frequency among site classes may be meaningful from a management standpoint, but the smaller differences among soil groups or slope positions may not be (fig. 2).

No significant relationship between dwarf mistletoe occurrence and tree diameter class was found on the Beaver Creek Watershed. This observation was contrary to that reported by Hawksworth (1961b), who stated that the frequency of the parasite increases with tree size. Cutting history apparently was responsible for this difference. On Beaver Creek, two cuttings have taken large mature and overmature trees, and in the last cut, mistletoe-infected trees were removed in preference to healthy trees.[3] Thus, the mistletoe problem can be expected to diminish if managers prescribe removal of infected trees in cutting guides.

Figure 2.--Proportion of inventory points with dwarf mistletoe infected trees within individual site classes, soil groups, and slope position.

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[3] *Personal communication from Norman E. Johnson, Timber Staff Officer (retired), Coconino National Forest.*

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Agriculture --- CSU, Ft. Collins

U S D A FOREST SERVICE
RESEARCH NOTE RM- 176

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Economic Value of Recreation Benefits Determined by Three Methods

Wendell Beardsley[1]

Consumer's surplus, monopoly revenue, and visitor survey methods all yielded value-per-visitor-day figures near $1, but total values differed considerably. The monopoly revenue method is freest of uncontrolled bias, but none of the three measures "market price" in the usual sense.

KEY WORDS: Forest recreational use, forestry business economics, recreation economics.

Introduction

Managers are encountering more and more con-
:ting demands for use of land and water
sources. Decisionmaking aimed at an "optimal"
ttern of use of natural resources must rely upon
ne measure of value to society of each possible
e. Market prices supply the appropriate measure
value in many instances, but in others, such as
recreational use of public wild lands, such prices
lacking. As a result, the decisionmaking process
frustrated, political pressures and emotion begin
dominate the process, and it is questionable
ether recreational resources are allocated in an
timum manner.

To relieve the need for recreation values, econo-
sts have devised several methods for imputing
lue to recreation benefits. Usually, when a
alue" for recreation benefits is wanted, one of
several methods is selected and its particular
ult used. Because the methods differ considerably,
ee of these, the consumer's surplus, monopoly revenue, and visitor survey methods, were compared in the present study. While the theory and methodology of these are omitted here, the results of an evaluation of one recreation area with each of the three methods are given, along with a few precautions for their interpretation. To indicate why we expect the different methods to yield substantially different results, a brief discussion of the concept of valuation that they use may be helpful.

Economic "value" is customarily equated with "price" for making resource allocation decisions affecting goods and services marketed in a competitive economy. But, because recreational use is not marketed, in the usual sense, we lack prices for such uses of many public wild lands. It should be noted that it is a common practice to use nonmarket-price values attributed to benefits of flood control, industrial and municipal water, and navigation, as well as recreation in analyses of water development projects. To aid decisionmakers, therefore, economists have developed the above methods to simulate how a market might operate to arrive at price as an indicator of value. Simulation of a market has the advantage that the difficulties of attempting to actually market recreation can be circumvented and the price a market would indicate can be estimated.

Although the three methods have this estimate as a common objective, they (1) define the relevant

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[1] *Research Economist with the Intermountain*
rest and Range Experiment Station, Ogden,
ah, which supported this study together with
Rocky Mountain Forest and Range Experiment
ation. Central headquarters for the Rocky
untain Station is maintained at Fort Collins
cooperation with Colorado State University.

price or value differently, and (2) they utilize quite different methods of measuring it. Two methods, the monopoly revenue and visitor survey techniques, approach the problem by estimating the level of attendance that would result at the area at each of several progressively higher admission charges. Each admission price, multiplied by its corresponding estimated attendance figure, yields the total revenue theoretically obtainable at that admission price. From a list of total revenues, the highest is chosen to represent the "market value" of recreation produced by the area. The admission price at which revenues are maximized is assumed to measure the "market value" per visitor-day. Of course, many visitors would not come at this price; we expect, therefore, that the attendance figure corresponding to the "optimum" price would be lower than the present level.

The third method (consumer's surplus) defines the relevant value differently. It assumes that each visitor places an intrinsic, unique, and somehow measurable value on his recreational experience. It attempts to measure this value from an analysis of the expenditure patterns of visitors from varying distances. Once measured, the "surplus" of value a visitor receives from his trip is easily measured as the difference between the intrinsic value of the visit to him and its cost. The summation of these differences, over all visitors, yields the total value obtained by recreationists. This value estimate corresponds, of course, to total present attendance at the area and not to a portion of it as do the previous two.

We expect then, if all three methods actually approximate a market price, that the values per visitor-day of recreation they yield should be nearly the same, even though the methodology they use is quite different. However, as described above, the values per visitor-day they provide apply to quite dissimilar numbers of recreationists. Because the consumer's surplus technique derives value per visitor-day and applies it to the total number of visitors, we expect its total value estimate to be proportionately larger than the monopoly revenue and visitor survey estimates based on some fraction of visitor use.

The Study Area

The three methods were compared by interviewing recreationists along a 7-mile portion of the scenic canyon of the Cache la Poudre River in northern Colorado. The area is within the Roosevelt National Forest, about 50 miles from Fort Collins. It consists of a glaciated valley with a broad flat floor at 7,600 feet elevation, and steep side walls which rise to over 10,000 feet. The river is considered one of the best trout streams in Colorado. Its scenic quality was recognized when it received "preliminary consideration" (along with 66 other rivers in the U. S.) by the Wild Rivers Study Team for possible inclusion in the Wild Rivers Bill which would have preserved the river in its free-flowing state.

Presently, recreationists camp, picnic, and fish at many developed and undeveloped sites along this section of the river. All sites are easily accessible from paved Colorado Route 14. The Forest Service has developed facilities at the Home Moraine interpretive display and the 15-unit Sleeping Elephant Campground.

Methods

Necessary data were gathered from on-site personal interviews with a 20-percent sample of recreationists during the summer of 1966. Place of origin and round-trip expenditures of visitors were obtained to permit valuation with the "consumer's surplus" and "monopoly revenue" methods. The third, and more direct, "visitor survey" method of valuation relied upon visitors' responses to a question, "How much more than your present costs of use would you willingly pay to use this area"

Briefly, the consumer's surplus and monopoly revenue methods proceed in the following way. Questionnaire answers were arranged according to the zone of origin of visitors. The eight zones were roughly concentric around the study site. For each zone, average cost per visitor-day[2] at the site was determined. The rate of use (visitor-days use per 100,000 population) was estimated from the population of the zone. The questionnaire data are summarized in table 1.

The visitor survey method derives the relationship between costs and use-rates more directly. The relationship is based on responses to the "willingness-to-pay" question. To minimize the obvious possibility of bias in the answers visitors gave for a question of this type, they were asked,

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[2] *One visitor-day is defined here as visitor-hours spent at the study area.*

Table 1.--Average total cost and use-rates of visitors by zone of origin

Zone	Round-trip distance	Visitor-days use		Cost per visitor-day[2]
		Per season[1]	Per 100,000 population per season	
	Miles	Number		
1	0- 100	2,511	4,577.3	$4.37
2	101- 200	1,576	2,179.5	4.13
3	201- 300	5,451	521.0	4.14
4	301- 400	334	151.0	7.37
5	401- 600	42	11.9	5.58
6	601-1,200	1,088	16.1	6.15
7	1,201-1,800	715	1.9	7.09
8	over 1,800	190	.1	10.83
Total or mean[3]		11,907		4.86

[1] Total visitor-hours per season divided by 12 (the number of visitor-hours per visitor-day).

[2] Travel plus on-site expenditures, as obtained from visitors' statements.

[3] Weighted for number of visitor-days and length of stay.

through a "bidding game" question, for the additional dollar cost they would incur rather than forego the visit.[3] As a matter of interest and for comparative purposes, they were similarly asked the additional round-trip travel time they would be willing to incur:

Zone	Willingness to-- Pay	Willingness to-- Travel
	(Dollars)	(Hours)
1	1.16	1.12
2	.87	.81
3	.91	.66
4	.95	.84
5	.34	.16
6	.53	.49
7	.78	.55
8	.94	.94
Mean[4]	0.90	0.76

Results

The value of the area's recreation benefits in 1966 was estimated by the three methods discussed above. Depending upon which method of valuation policymakers designate as appropriate, recreation benefits for the 7-mile portion of the Cache la Poudre River in Colorado were worth approximately either $4,000 or $13,000 in 1966. The estimates are presented in table 2, together with capitalized values of future benefit streams at two different interest rates. The capitalized value figures explicitly assume constant future benefits at the 1966 level.

"Visitor-days use" and "total 1966 value" figures differ significantly between (1) the consumer's surplus estimate, and (2) the monopoly revenue and visitor survey estimates, because they define the relevant use level differently, as discussed previously. Of interest is the similarity of all figures for the monopoly revenue and visitor survey methods, and the near coincidence of all three "value per visitor-day" figures. The agreement between the monopoly revenue and visitor survey estimates of "an optimal price" lends a measure of confidence to their ability to estimate the value they aim at. All three "value per visitor-day" figures are clustered near $1, increasing our confidence in their ability to give consistent estimates of the value of a day's use of the area to visitors.

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[3] *While being an obviously difficult question and one for which accuracy of answers may be suspect, this approach has been used in attempting to define demand for recreation. For example, see: Jack L. Knetsch and Robert K. Davis. Comparisons of methods for recreation evaluation. Water Research, ed. by A. V. Kneese and S. C. Smith. 526 p. Baltimore: The Johns Hopkins Press. 1965.*

[4] *Weighted for number of visitor-days and length of stay.*

Table 2.--1966 benefits and capitalized value of recreation at the study site by three economic methods

Method	Value per visitor-day	Estimated visitor-days use	Total 1966 value	Capitalized value at 3 percent	Capitalized value at 8 percent
Consumer's surplus	$1.07	11,907	$12,740	$424,700	$159,200
Monopoly revenue	.93	4,321	4,020	134,000	50,200
Visitor survey	1.11	4,803	5,330	177,700	66,600

Discussion

Estimates of value in the form of an imputed price of benefits of wild land recreation can be developed by economists and are much easier to obtain compared to actually establishing a market for recreational use and observing visitor's responses to different prices for visitation. These estimates may be useful in making decisions about resource allocation. The comparison of methods presented in this study should aid in the selection of an appropriate technique in other valuation problems. Perhaps the most interesting aspect of this comparison is the clustering of the value-per-visitor-day figures near $1. But it is obvious that estimates of total value yielded by different methods are not close together. Less obvious, but more important from an economical point of view, and the reason for much of the differences, is that the methods do not attempt to measure exactly the same thing. As discussed above, a fundamental difference between the methods is the number of visitors their value estimate is applied to. All attempt to estimate the value of a day's recreation; for the consumer's surplus method, this value is multiplied by total present use to obtain the total value of benefits; for the visitor survey and monopoly revenue methods, this value is multiplied only by that portion of present use that could be expected to willingly pay this amount for use of the area in the form of an entrance fee. It is common for development agencies to use the former (total use) approach even though it is obvious that this is not consistent with the usual concept of the price-quantity relationship determined in a market.

Finally, two notes of caution must be mentioned in connection with the use of such value estimates. First, many other valuation studies have incorporated bias from several sources (some of considerable magnitude) into the value estimates. Some, but not all, of the bias factors can be and were corrected for in this study. While this considerably improves them, none of the methods precisely measures the figure it seeks. When they are used, the presence of uncontrolled biasing factors should be recognized.

Secondly (and more important), even if the simulation processes of the methods were unbiased, the sought-out value figures are not "market prices" in the usual sense. They represent a measure of value to visitors, but were not arrived at through the interplay of the usual "supply and demand" forces of an actual market. Therefore, to compare such values directly with market values (or any other kind) would be misleading.[5]

For the various reasons discussed above, it can be concluded that some skepticism may be called for when judging estimates of recreation value put forward in plans for recreation development. The need for a uniform policy determination of the appropriate use level to use in benefit calculations is obvious. However, until benefits of other resource uses are determined by methods comparable to the consumer's surplus technique, values more closely approximating a market price are provided by the visitor survey and monopoly revenue approaches, of which the monopoly revenue technique is most free of uncontrolled sources of bias.

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[5] *For more detailed discussion, see: Wendell Beardsley. Bias and noncomparability in recreation evaluation models. Accepted for publication (early 1971) in* Land Economics.

U S D A FOREST SERVICE
RESEARCH NOTE RM-177

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Improving Survival of Alkali Sacaton Seedlings Under Adverse Conditions[1]

Earl F. Aldon[2]

Alkali sacaton (Sporobolus airoides (Torr.) Torr.) seedlings have little chance of surviving adverse field conditions unless seeds are planted on moist soil, on an agar plate, under mulch, and watered after 5 days.

KEY WORDS: Sporobolus airoides, plant physiology, plant water relations, seed germination.

Previous work (Aldon 1969a, Knipe 1968) has vn alkali sacaton requires almost zero soil mois- tension to germinate (at 85° F.), and must ive water sometime between the 5th and 10th after planting to get adequate germination. sequent work (Aldon 1969b) has shown it is ible to germinate alkali sacaton on relatively soils under greenhouse conditions if agar plates used to supply moisture. Pilot tests were made etermine whether alkali sacaton could be estab- ed under circumstances resembling field condi- s found on the Rio Puerco drainage. Survival 5 days after planting was the goal, since natural precipitation must sustain the young plant in the field. Seeds must be planted, therefore, when probabilities for precipitation are greatest. On the Rio Puerco drainage, this is the last week in July and early August (Gifford et al. 1967).

Methods

A vacant lot used for outdoor storage and parking in Albuquerque, New Mexico, was chosen as a severe test site. This harsh site maintains little or no perennial vegetation. It has been periodically scraped by a road grader, and blowing sand deposits on it. To test methods of plant survival, a protected portion of this site was used in June, normally a dry month in the Southwest.

A randomized block design was used with eight treatments and four replications. Treatments included rewatering after 5 and after 5 and 10 days, planting on wet soil under 1/2 inch of vermiculite or perlite mulch, and addition of a 2 percent agar plate between soil and mulch. Ten seeds were planted in each treatment. A 6.5-inch-diameter collar was

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[1] *Study conducted in cooperation with the .S. Bureau of Land Management, Albuquerque, Mexico.*

[2] *Principal Hydrologist, located at Albu- rque in cooperation with the University of Mexico; central headquarters maintained at Collins, in cooperation with Colorado te University.*

Figure 1.--Shown are three of the four replications of eight treatments used in the study. Collars are about 3 inches above the ground and 1 inch in the ground.

placed 1 inch into the ground and filled with about 3 inches of water. Water was allowed to soak into the soil before planting (fig. 1), which took about 20 minutes.

A thermograph was maintained in a standard shelter on the site near an 8-inch standard precipitation gage.

Air temperatures ranged from a high of 99° F. to a low of 49° F. Daily averages ranged from 70° to 81° with an average of 75° F. High temperature readings lasted about 2.5 hours in the late afternoons.

Living plants were counted on the 9th, 12th, and 15th day after planting. A statistical analysis was performed using $\sqrt{x + 3/8}$ transformation of the data.

On the second day after planting, the site received 0.23 inch of precipitation; on the fourth day, 0.50 inch precipitation fell. No 5-day rewatering was needed as the natural precipitation was considered adequate. On the tenth day, 0.25 inch of water was applied to appropriate treatments.

Results

The treatments were statistically different since the check plots had no survival. Fewer plants were counted on each successive date so that by the end of the study an average of 4.29 plants were left in each collar. The 9-, 12-, and 15-day average counts for all treatments were significantly different (table 1). When all of the 10-day treatments were compared with similar 5-day treatments, the 10-day group proved superior.

Agar and vermiculite at planting proved superior to the plain perlite or vermiculite treatments only if plants received water after 5 days (table 1).

Table 1.--Average number of plants surviving under various treatments 9, 12, and 15 days after planting

Treatment (Mulch & watering schedule)	Plants surviving, by days since planting--		
	9 days	12 days	15 days
		- - Number - -	
Agar-vermiculite:			
5 days	6.75	6.25	5.50
5 & 10 days	7.00	6.25	5.00
Vermiculite:			
5 days	4.00	3.00	3.25
5 & 10 days	7.75	5.25	4.50
Perlite:			
5 days	3.00	2.50	2.75
5 & 10 days	5.25	5.75	4.75
Check (control):			
5 days	0	0	0
5 & 10 days	0	0	0
Average	5.62	4.83	4.29

Conclusions

Initial survival is best when alkali sacaton seed- ngs receive moisture at 5-day intervals. Over alf can survive for 15 days, if agar is used to nhance germination and they receive moisture ter the fifth day.

To get alkali sacaton to survive, the following needed:

- Plant on moist soil with a 1/2-inch vermiculite or perlite mulch when temperatures are around 85° F.
- Place a 2 percent agar plate between seed and soil to reduce moisture tensions for the germinating seeds.
- Water after 5 days if no natural precipitation occurs (at least 0.25 inch).
- Plant at a time when the probability for rain or flooding for 15 days is above 80 percent. In the Southwest on the Rio Puerco, this is in late July or early August.

This is the first information obtained on how to ake alkali sacaton survive under these adverse nditions. Additional work will need to be done put these results on an operational basis.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-178

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Dispersal Studies With Radioactively Tagged Spruce Beetles[1]

J. M. Schmid[2]

Adults of the spruce beetle, Dendroctonus rufipennis (Kirby) (Coleoptera: Scolytidae), were tagged with radioactive iodine (I-131) and released to determine dispersal characteristics. About 4 percent were recovered. More beetles were recovered in easterly than in westerly quadrants, possibly because of light but variable westerly winds. Dispersal continued for 7 to 8 days after release. Beetles attacked the closer sample trees first and then more distant trees. Beetles infested with nematodes dispersed as far and in the same pattern as noninfested beetles.

KEY WORDS: *Dendroctonus rufipennis*, *insect behavior*, *iodine isotopes*, *radioactive tracers*.

Trap trees are frequently used to reduce or trol localized populations of the spruce beetle, *ndroctonus rufipennis* (Kirby). This method con- gates the beetles by capitalizing on their natural action to freshly downed logs. Its success, how- r, depends partially on knowledge of the beetle's ht and dispersal habits. This Note reports on dies, conducted on two National Forests in Colo- co in 1953 and 1954, designed to investigate se habits.

Methods

Hibernating adults were collected from the bases of infested trees on the White River National Forest in June 1953 and on the Uncompahgre National Forest in June 1954. Groups of 1,000 beetles (plus frass and bark) were spooned into pint cartons containing moist peat moss, and stored at 35° to 40° F.

Just prior to release, the beetles were removed from cold storage and allowed to regain field temperature. Groups of beetles were then immersed in a chilled 20 percent ethanol solution of radioactive iodine, I-131, in the release area.[3] After excess solution drained from the beetles, they were tumbled from the immersion vessel onto trays of aluminum foil. The trays were then transferred to preselected release points in the timber, and placed

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[1] Research reported here was conducted by H. Nagel, Entomologist, Rocky Mountain Sta- n (now retired), J. M. Davis, Entomologist, tsville Forest Insect Laboratory, Belts- le, Maryland (now deceased); and A. E. dgraf, Jr., Graduate Student, Duke Univer- y (now Entomologist, U. S. Forest Service, hington, D. C.)

[2] Entomologist, Rocky Mountain Forest and ge Experiment Station, with central head- rters maintained at Fort Collins in cooper- on with Colorado State University.

[3] Davis, J. M., and Nagel, R. H. A technique for tagging large numbers of live adult insects with radioisotopes. J. Econ. Entomol. 49: 210-211. 1956.

on the ground in shaded locations. One release point was established in each release area. The transfer and placement procedure held the gamma radiation at a safe level in the vicinity of the immersion apparatus, and prevented beetle mortality from exposure to direct sunlight. The immersion process usually left the beetles motionless for 15 to 30 minutes, and direct exposure to sunlight would have killed a high percentage of them. Bits of bark and twigs were added to the trays to provide additional protection and serve as points from which the beetles could fly. The immersion and release of 1,000 beetles took about 2 hours.

Beetles were released in even-aged, well-stocked stands of mature Engelmann spruce (Picea engelmannii Parry) on flat terrain in Colorado. Of the 42,700 beetles released during the study, 19,600 were released on the Routt National Forest in 1953, and 23,100 were released on the San Juan and Routt National Forest in 1954.

Sampling points were established at 20-chain intervals on a grid around the point of release (fig. 1). Sampling points were also located along the four cardinal directions at distances of 60 ad 80 chains from the release point. This design p-vided sampling points in 24 directions, at distancs from 14 to 80 chains.

At each sampling point, a green spruce tre was felled in an east-west direction about 1 wek prior to beetle release. Since spruce beetles prer shaded bark in which to construct egg gallers, the trees were not limbed until after beetle relea. Felling the trees just prior to beetle release redud the possibility of attacks by Ips or nontagged spre beetles.

Scintillation counters were used to detect taggd beetles after they attacked the trees. During e first week after release, bark surfaces were scannd daily with the counters held 1 to 2 feet aw. Three weeks after release, radiation was so redud that the instruments had to be held within 1 in of the bark surface. Detection of radioactive beets was considered questionable 3 weeks after relea.

Weather conditions during the release peris and for at least 1 week thereafter were genera fair. Winds were generally westerly but rary exceeded 5 m.p.h. in the stand. Daytime te-peratures were usually in the 60° to 70° F. ran. Intermittent afternoon showers fell regularly.

About 180 beetles were relocated and examind for nematodes in 1954.

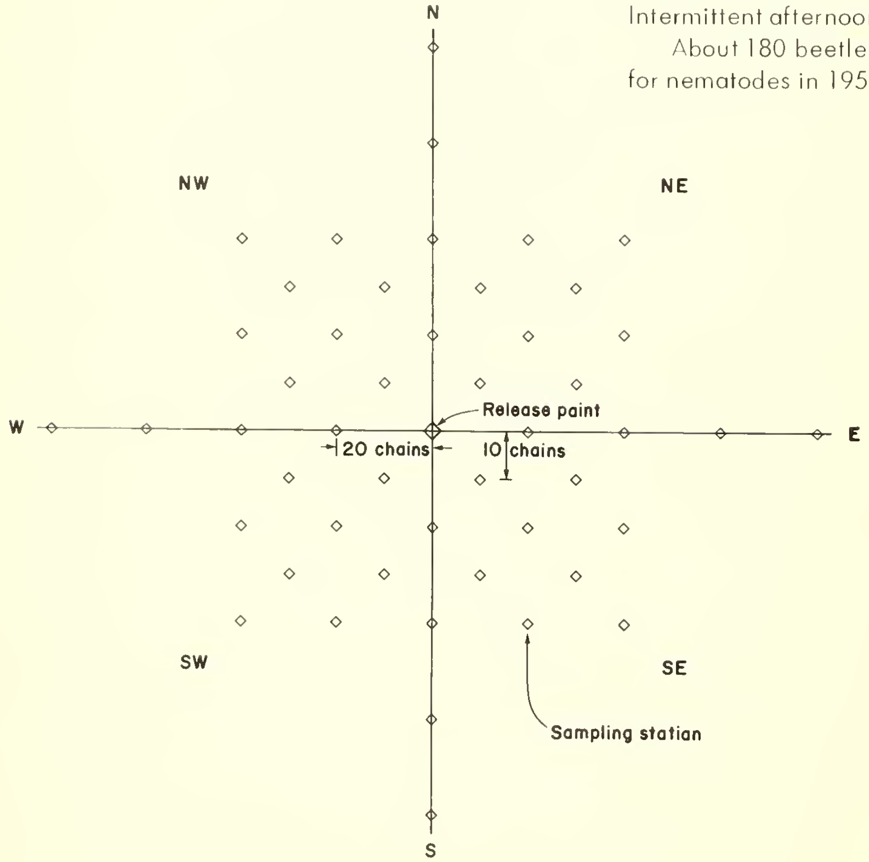

Figure 1.--Design of the sample point gd system around a release point. Maximum samplin distance from release point was 80 chains.

Results and Discussion

Beetle Recovery

Of the 42,700 tagged beetles released, only ,569 were recovered—an average of 4.4 percent or less in both years:

Date and location of release	Beetles-- Released (No.)	Recovered (No.)	(Pct.)
July 17, 1953 Routt NF	19,600	669	3.4
June 28, 1954 San Juan NF	4,300	69	1.6
July 3, 1954 Routt NF	18,800	831	4.4

Beetle recovery by quadrants was: northeast, 408; southeast, 454; southwest, 353; and northwest, 354. Ninety-seven beetles traveled 60 or more chains from the release point.

The reasons for the low recovery of beetles are not all known. About 15 percent of the beetles failed to leave the release stations. This loss was attributed to natural mortality and the effects of the radioactive material. The sampling system may be involved. Probably an undetermined number of beetles were lost because they attacked natural windfalls within the test area, but windfalls were neither counted nor surveyed for tagged beetles. Also, some beetles may have flown beyond the limits of the test area (80 chains). Since 6 percent of those recovered (97 beetles) flew 60 chains or more, perhaps a portion of the test population flew beyond the outer sampling stations.

Dispersal

Direction of beetle dispersal was not uniform. Significantly more beetles were recovered in easterly than in westerly quadrants. Although windspeed during the release period rarely exceeded 5 miles per hour, the winds were generally from the west, which may account for the greater number of beetles recovered in the easterly quadrants.

Beetles continued to disperse for 7 to 8 days after release, but on the 20- and 40-chain sample trees, the greatest number of attacks were made within 3 to 5 days. The 1953 average daily count of beetles per tree on sample trees on each of the four cardinal directions at the 20- and 40-chain distances was:

Days since release:	20 chains (No. of beetles)	40 chains
2	2	0
3	20	2
4	27	3
5	32	3.2
6	34	4.6
7	36	4.6
8	33	3.2

Attacks at the 14-chain sample trees began the day after release, and were so numerous that a daily rate of increase could not be determined. Recoveries at the sample trees 60 or more chains from the release point were insufficient to measure daily increases. Equal numbers of males and females were recovered, both far from and close to the release point.

Trap Tree Location

The decrease in density of attacks with distance from the release point indicates that beetles may first attack the closest suitable host material, and then progressively work out to more distant material. This suggests that trap trees should be located at least within 10 to 20 chains of infested material or they may not be effective. The decrease in time of initial attack also supports this idea because the closer trees were attacked first. The 3- to 5-day interval between time of release and attack also suggests that trap trees 40 or more chains from an infested area might not be effective because beetles could locate closer suitable host material prior to locating the trap trees.

The decrease in the average daily counts of attacks was apparently due to re-emergence of the adults. This suggests that an adequate number of traps be felled so that, if beetles re-emerge and attack again, the traps could absorb them.

Dispersal of Beetles Infested With Nematodes

Beetles infested with nematodes dispersed in the same pattern as noninfested beetles. About equal numbers were recovered from the sample trees located 40 to 80 chains from the release point as well as from those trees 0 to 32 chains distant. This suggests that nematodes may not seriously affect the beetle's ability to disperse.

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USDA FOREST SERVICE
RESEARCH NOTE RM-179

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Some Cone and Seed Characteristics of Black Hills Ponderosa Pine

James L. Van Deusen
and Lawrence D. Beagle[1]

Selected characteristics were obtained from 75 sample trees distributed among 6 relatively distinct collection areas. Cone lengths were quite uniform, averaging 2.6 inches over the area; number of seeds per pound averaged 12,673, but ranged from 8,247 to 22,997 from individual trees. Number of seeds per cone was related to cone length. Green cones per bushel averaged 415.

KEY WORDS: Pinus ponderosa, forest seed production, forest seed collecting.

Introduction

Results presented in this Note were obtained part of a larger, continuing study of racial varia- in Black Hills ponderosa pine (*Pinus ponderosa* s). The purpose of the Note is to indicate the iability of selected cone and seed characteristics in the Black Hills, and to provide guides for foresters to aid their cone (seed) collecting activities. Characteristics discussed are average cone length, number of seeds per pound, number of seeds per cone and its relation to cone length, number of cones per bushel, and some of the variations in seed color and marking. Some practical applications of this information are also suggested.

Methods

Cone collections.—The Black Hills were divided into six distinct cone collecting areas, based primarily on geologic formations and latitude (fig. 1). The

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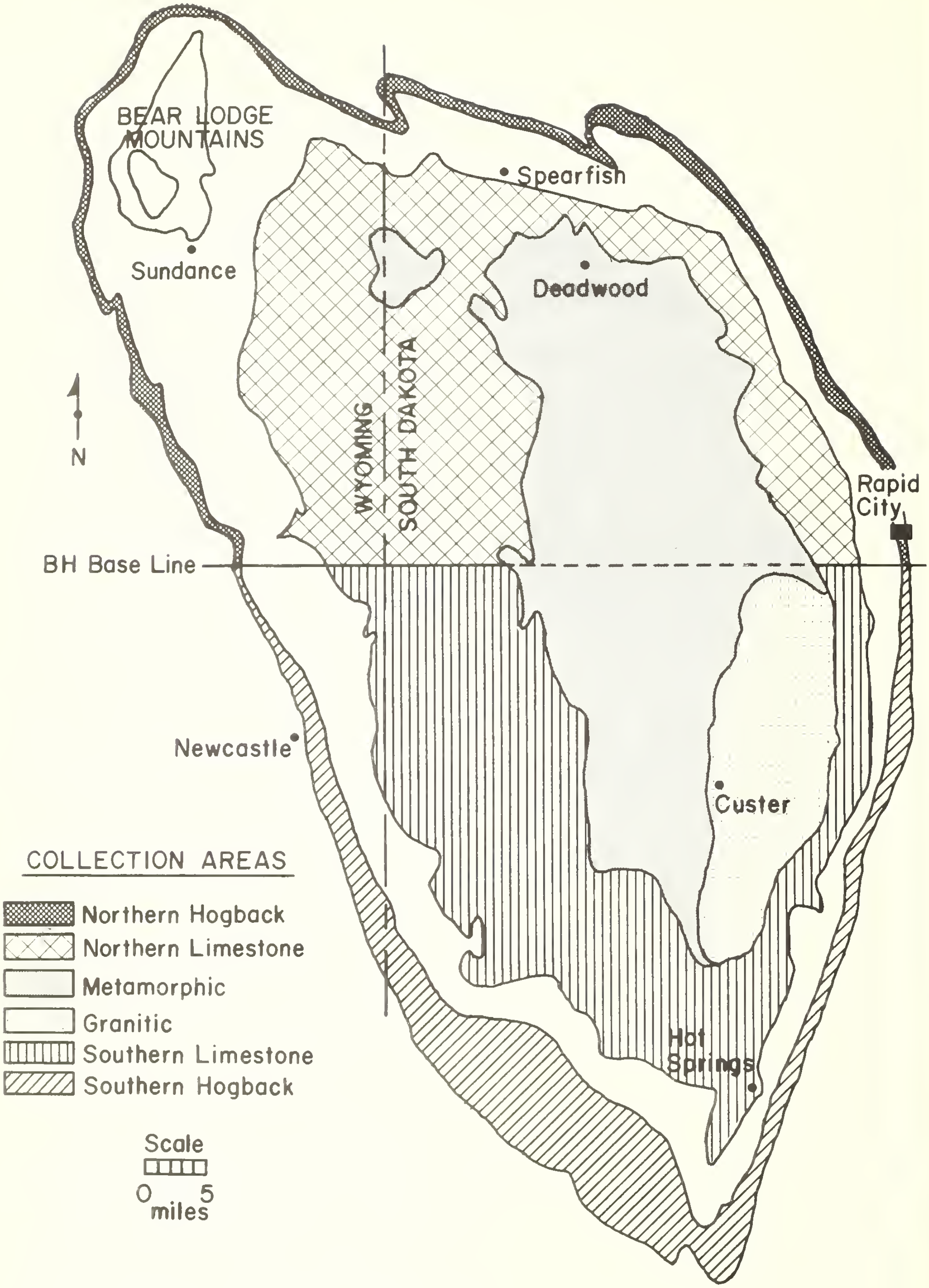

Figure 1.--Location of cone collection areas in the Black Hills. Bear Lodge Mountain collections were unsatisfactory.

Black Hills Base Line separated the Black Hills limetone and hogback collection areas into "northern" and "southern" subdivisions. The collection areas were identified as: southern hogback (SH); southern imestones (SL); granitic (G); metamorphic (M); northern limestones (NL); and northern hogback (NH). welve trees were sampled in each area, except M (16 trees) and NH (11 trees), for a total of 75 rees.

Cones were collected from upper crowns of trees which were better than the average of nearby trees of the same age. Ten to thirty cones were picked rom each tree, except for one tree which had produced only six usable cones. One cone, the fifth gathered from each tree, was individually bagged within the cloth bag with the rest of the cones from hat tree. These cones will later be referred to as he "single" cones, while the remaining cones from each tree will be known as the "bag" of cones.

Most of the cones were collected during the fall of 1967. Area NH was sampled in the fall of 1968, because cone ripening and subsequent seed fall had begun before it could be sampled in 1967.

In two separate years attempts were made to collect cones from trees in the Bear Lodge Mountains of Wyoming. The 1968 crop was large enough or collection, but seed quality was too low to give meaningful information. Production in 1969 was too scanty to provide a sufficient number of cones and seed to study; in fact, few trees produced any cones.

Additional cones were collected in containers of known size from eight locations scattered throughout the study area. Each container was level-filled with cones from at least three trees at each location. The green cones in each container were counted and converted to number of cones per bushel.

Cone and seed handling.—The cones from each sample tree were hung in a heated room until air-dry. Each of the 75 single cones was then measured and completely emptied of seed. Some of the cones had to be torn apart to extract the seeds.

The longest and shortest cone in each bag of cones were also measured. An average cone length, based on three cones (single, longest, and shortest), was computed for each tree. The cones in each cloth bag were then vigorously shaken individually and collectively to extract all seeds that would shake out. Shaking was intended to simulate the tumbling action normally used in seed extraction.

Extracted seeds were carefully dewinged, cleaned, and counted. Average number of seeds per cone was computed for each tree. A sample of completely clean seeds from each tree was weighed and converted to number of seeds per pound. At least 200 seeds were included in each weight sample; most samples contained 500 to 1,000 seeds.

Table 1.--Selected cone and seed characteristics of ponderosa pine in the Black Hills, 1967 and 1968

Area[1]	Number of trees sampled	Cone lengths		Sound seeds per cone		Sound seeds per pound	
		Average	Range	Average	Range	Average	Range
		- - Inches - -				- - Number - -	
SH	12	2.62	1.75 - 3.62	60.1	45.4 - 81.1	10,223	8,247 - 15,120
SL	12	2.88	1.94 - 3.94	64.4	26.3 - 88.8	11,969	8,725 - 13,567
G	12	2.62	1.50 - 3.25	58.4	17.5 - 83.9	13,462	10,643 - 15,120
M	16	2.58	1.44 - 3.81	45.7	29.3 - 80.8	13,393	9,923 - 20,082
NL	12	2.59	1.44 - 3.31	60.5	19.7 - 88.8	14,122	10,162 - 22,388
Weighted average, 1967 collections		2.65		56.9		12,673	
NH	11	2.44	1.69 - 3.69	43.6	24.4 - 66.6	15,142	11,569 - 22,997

[1] NH cones collected in 1968; all others in 1967.

Results and Discussion

Average cone length.—There was about a 2-inch range in cone length in all areas, but the range in average lengths was only 0.44 inch, Hills-wide (table 1). Only cones that appeared capable of yielding viable seed were collected, so abnormally small cones were not represented.

Number of seed per pound.—This characteristic, an indirect expression of seed size and density, was extremely variable both within and between areas (table 1). The range among all sample trees was from 8,247 to 22,997 seeds per pound. This extreme variability in seed weights suggests that an overall average number of seeds per pound is probably of questionable value as an indicator of the size of seeds that might be collected in any particular stand.

Area averages, however, seem to indicate a fairly steady increase in average number of seeds per pound from south to north (table 1). Because data from the northernmost area were collected in 1968, they may not be comparable to data from the 1967 collections. They do maintain the trend toward larger numbers of seeds per pound as one goes north, however. Whether this is a real area difference that would show up consistently is open to speculation. Annual precipitation generally follows a parallel trend—highest in the northern Black Hills and lowest on the southern hogback of the Black Hills.[2]

Large seeds normally produce large seedlings. Since large seedlings may be better equipped for survival in a harsh environment, the large seed trait of the southern sources may be an adaptation to the hotter, drier climate of those areas.

Considering the large variability among trees throughout the Black Hills, our calculation of the weighted average at 12,673 seeds per pound is remarkably close to the average of 12,730 for Black Hills pine obtained over a 4-year period by the Mt. Sopris Nursery.[3] Carlos Bates, who directed seed collections for 8 years from dominant and co-dominant pines, reported an average of 17,842 seeds per pound.[4] His collections, however, were restricted to a single area of about 10 acres in th southern Hills. Roeser,[5] reporting on 7 years o seed collection on the Fremont Experimental Fores in Central Colorado, found an average of 14,72 seeds per pound.

Cones per bushel.—The average number of gree cones per bushel was 415, with a standard deviatio of 51. Bates found an average of 498 cones pe bushel, with a range of 444 to 548. Bates' cone may have been smaller because he collected fro codominant as well as dominant crown classes, whil we collected from dominant trees only. The M Sopris Nursery average, 250 cones per bushel fro Black Hills ponderosa pine, may be lower becaus cones are at least partially open by the time the reach the nursery.

Seeds per cone.—Our sample of about 1,10 cones produced an average of 57 sound seeds eac (table 1). Numbers of obviously defective see were negligible. Although Bates found an averag of only 32 seeds per cone in a study with 10 time as many cones, his sample came entirely from on limited area, and the cones were smaller.

In the normal seed-extraction process, some see remain in the cones and are discarded with the How many seeds are lost is indicated by the diffe ence between the regression lines in figure 2. Th lower line is based on the number of seeds r covered from the bag of cones, where seeds we extracted by merely shaking the cones (data use in table 1). The upper line is based on the numb of seeds found when single cones were complete pulled apart. An average of 6 seeds was left in 2-inch cone after shaking (or tumbling) while average of 19 seeds remained in 3.5-inch cone Since about 10 seeds would be retained in th average 2.6-inch cone found in this study, abo 1/3 pound of seeds would be lost in each bush of discarded cones.

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[2] *Orr, Howard K. Precipitation and streamflow in the Black Hills. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta., Sta. Pap. 44, 25 p., illus. 1959. Fort Collins, Colo.*

[3] *Personal communication with Rodney W. Ellis, Nurseryman, Mt. Sopris Nursery, March 17, 1969, on file at Rocky Mt. Forest and Range Exp. Sta., Rapid City, S. Dak.*

[4] *Unpublished data on file at Rocky M Forest and Range Exp. Sta., Rapid City, Dak.*

[5] *Roeser, Jacob, Jr. Some aspects of flow and cone production in ponderosa pine. J. Fo est. 39:534-536, illus., 1941.*

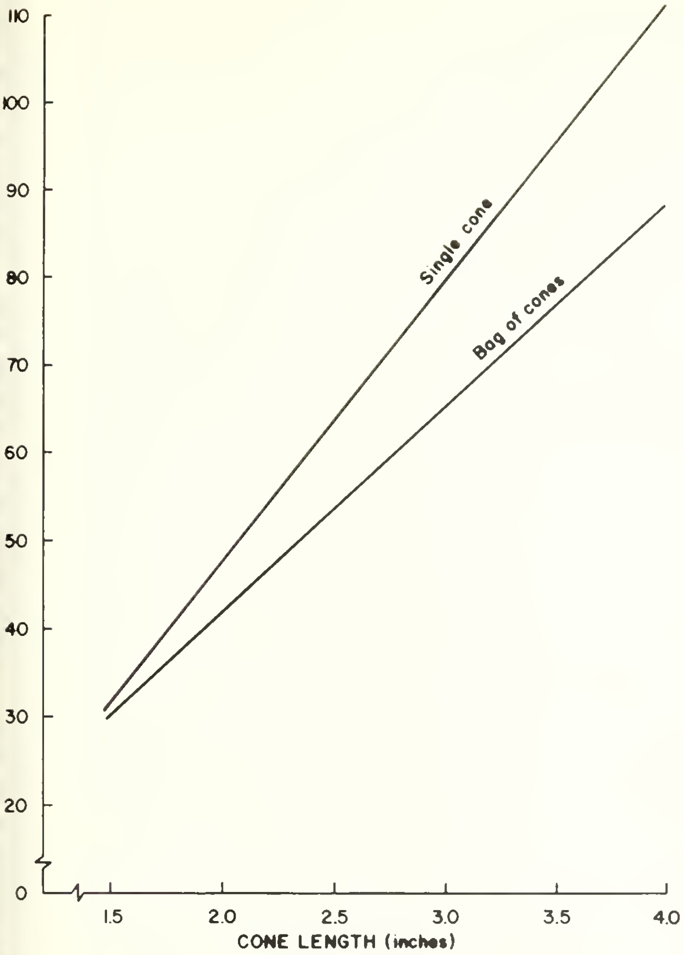

Figure 2.--Relationship between number of seeds per cone and cone length. Upper line represents the single cone, which was completely emptied of seeds. Lower line represents an average from the bag of cones when seeds were extracted by merely shaking the cones.

Equations	r	Standard error of estimate	Basis
$Y_1 = 31.78X_1 - 16.04$	.52**	22.2 seeds	59 trees
$Y_2 = 23.01X_2 - 4.22$	.41**	16.1 seeds	62 trees

where:

X_1 = Cone lengths of 1.75 to 3.88 inches (upper line)

X_2 = Cone lengths of 2.02 to 3.42 inches (lower line)

Seed coloring.—Tree-to-tree variability in seed arking and coloring was large and distinct (fig. 3), hile all seeds from any one tree were essentially dentical in color and marks. Seeds from some ees were a uniform light gray and some were early solid black. Some trees produced light-olored seeds with dark spots, and from other trees the seeds tended toward dark stripes on a light background.

Practical implications of this sort of variation, if any, are unknown. Seedcoat color and markings may have evolved simply as camouflage for seeds on the ground. There did not seem to be any link between seedcoat appearance and any of the desirable tree characteristics of greater growth and freedom from insect or disease attack stressed in sample tree selection.

Bear Lodge Mountain data.—A combination of moderately heavy insect damage and large numbers of unfilled seeds made seed data from the Bear Lodge Mountains worthless. Insect-damaged cones were pitchy, failed to open satisfactorily, and contained many seeds with insect borings. The specific damage-causing insect is not known. The large number of unfilled seeds was probably due to a combination of factors associated with pollen and its dissemination. Cone characteristics such as average length and number per bushel were much the same as for the Black Hills proper.

Management Applications

To illustrate the use of this information, suppose a forester was asked to collect 50 pounds of pine seed. How many cones, or bushels of cones, would he need?

If he planned to collect in several widely scattered locations throughout the Black Hills, he could expect cones to average 2.6 inches in length and yield 57 seeds per cone (table 1). Therefore, it would take 222 cones (12,673 divided by 57), on the average, to yield a pound of seeds. He would then need 50 times 222, or about 11,100 cones. In terms of bushels, he would need 11,100 divided by 415, or 27 bushels.

On the other hand, suppose his collecting area was located entirely on limestone soils in the southern Hills. He might then expect his larger cones (2.9 inches) to yield about 64 seeds each. Approximately 12,000 seeds are required to make a pound, or about 188 cones. It would then require 50 times 188 divided by 415 or 23 bushels to yield 50 pounds of seed.

Because of possible year-to-year variations in cone and seed characteristics, collectors should first sample the current cone crop to check the applicability of these recommendations. The most likely source of unpredictable variation is in average number of sound seeds per cone. Averages of cone length, number of cones per bushel, and number of sound seeds per pound are less likely to show large year-to-year fluctuations.

In any event, we suggest that one collect a little more than his calculations indicate will be required, on the average. It is better to have too much than not enough, but these quantitative expressions of cone and seed characteristics should provide useful guides.

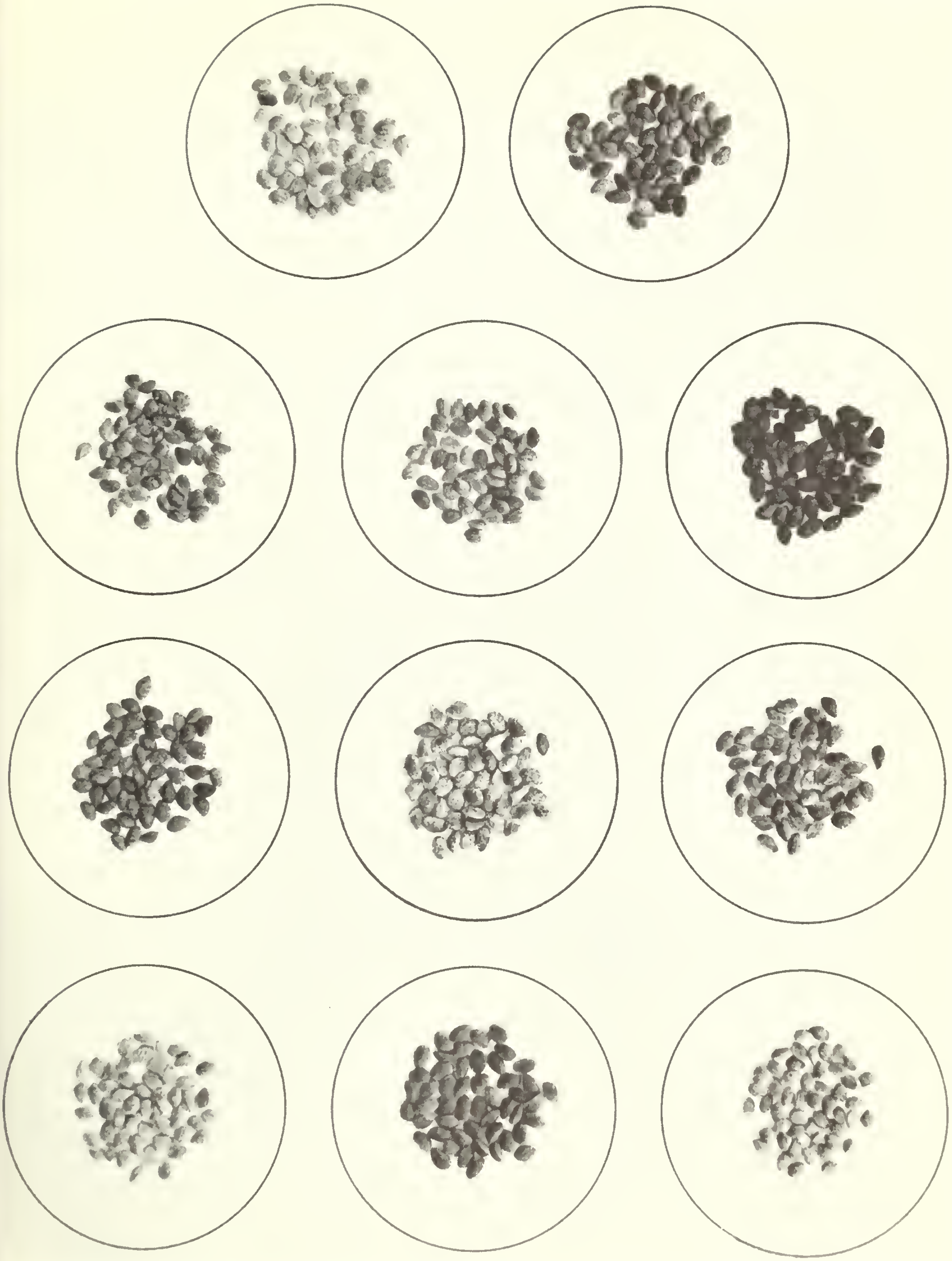

Figure 3.--Color and marking variations among seeds collected from northern hogback (NH) area. Each circle contains 50 seeds from a single tree.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-180

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

BRISTLECONE PINE-- Its Phenology, Cone Maturity, and Seed Production in the San Francisco Peaks, Arizona

Gilbert H. Schubert
and W. J. Rietveld[1]

Vegetative buds start swelling early in June, with bud-bursting and active elongation in mid-June. Male flowers are mature and release pollen by late July. Seed viability is strongly correlated with specific gravity (drying, maturity) of cones on the tree. Cones are uniform in shape, but vary greatly in size. Number of sound seeds per cone is strongly correlated with total seeds, but only weakly correlated with cone specific gravity and length.

KEY WORDS: Pinus aristata, forest seed production, cone collecting.

Bristlecone pine (*Pinus aristata* Engelm.), a sub-lpine species, occurs in widely scattered areas ı the mountains of eastern California, Nevada, Jtah, Colorado, northern Arizona, and northern Jew Mexico (Critchfield and Little 1966). Bristle-one pine normally attains a height of only 15 to 0 feet and a diameter of 12 to 18 inches. The ee, noted for its long life (Ferguson 1968, Fritts 969, Schulman 1958), is intolerant of competition nd is replaced by the more tolerant spruces (*Picea* pp.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) ranco), and true firs (*Abies* spp.). Bristlecone ine is valuable mainly for its use in dating events, s natural esthetics on high mountain slopes, its oils building and stabilization in inhospitable environments, and its ecological significance to animals and other plant associates.

In several pines, specific gravity of maturing cones has proved to be a reliable index of the ripeness of the enclosed seeds. The specific gravity required for acceptable germination has been determined for sugar pine (*Pinus lambertiana* Dougl.) (Fowells 1949), ponderosa pine (*P. ponderosa* Laws.) (Maki 1940), and Jeffrey pine (*P. jeffreyi* Grev. & Balf.) (Schubert 1955). Present literature provides ample references to dendrochronology, but very little is available on the seeding habits of bristlecone pine. Phenological observations, cone maturity indicators, and seed yields for bristlecone pine are presented here.

Study Area and Methods

Flowers and cones were collected from a young stand of bristlecone pines along the west edge of the San Francisco Peaks Natural Area. This stand, at an elevation of 9,500 to 9,680 feet, is located about 11 miles north of Flagstaff, Arizona (fig. 1).

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[1] *Principal Silviculturist and Associate lant Physiologist, respectively, located at lagstaff in cooperation with Northern Arizona niversity; central headquarters maintained at ort Collins in cooperation with Colorado tate University.*

Figure 1.--The study area--a thrifty stand of young bristlecone pine at 9,500 to 9,680 feet elevation on the west slope of the San Francisco Peaks in northern Arizona.

The site is characterized by a cold-moist climate (table 1). Mean monthly temperatures during a 3-year period ranged from 23° F. in January to 57° F. in June. During the winter months, the temperature dropped to -4° F., about 15° warmer than at Fort Valley Experimental Forest for the same time period. The maximum temperature seldom exceeded 90° F., with a mean maximum of about 68° F. in June. Precipitation averaged about 35 inches—12 inches more than at the base of the mountain.

The study area consists of a nearly pure stand of young bristlecone pines. This natural stand, which started about 50 years ago on an open grass site, is increasing in area. Just above the plot, older bristlecone pines are associated with quaking aspen (Populus tremuloides Michx.), Engelmann spruce (Picea engelmannii Parry), white and corkbark firs (Abies concolor (Gord. & Glend.) Lindl. and A. lasiocarpa var. arizonica (Merriam) Lemm.), and Douglas-fir.

Four cone collections of 20 to 30 cones each were made in the young stand during the fall of 1968, and another of 460 cones in 1969. The 196 collections were spread over a 9-day period startir on September 24. Cones from each collection wei measured shortly after picking to obtain data c cone length, width, weight, and volume.

Individual cones were then placed in small pape bags and allowed to open in a growth chamb set at an alternating temperature of 70° to 90° Number of days to open and total number of seec was determined for each cone. The seeds wei then stored at 0° F. until September 3, 1969, whe a germination test was started. At the conclusio of the germination test, all ungerminated seec were cut open to determine soundness.

Cones were collected in 1969 to obtain da on cones and seeds per bushel and per 100 pound specific gravity of open cones, and moisture conte of extracted seed. Cones that failed to open withi 4 days at a temperature of 70° to 90°F. were di carded as being of questionable maturity.

In 1969, flower development was observed fro June until ovulate strobili received pollen.

ble 1.--Mean monthly temperature and precipitation at an elevation of 9,400 feet on west slope of the San Francisco Peaks, Arizona, 1917-19

Month	Temperature				Average precipitation
	Maximum	Mean	Minimum	Lowest	
	- - - - -°Fahrenheit - - - -				Inches
nuary	29.5	22.9	16.5	-4	1.85
bruary	30.0	23.7	17.4	3	3.13
rch	35.0	27.3	19.6	12	3.89
ril	44.6	36.0	27.5	16	2.24
y	50.9	41.4	31.9	21	1.44
ne	68.2	57.2	46.2	37	.66
ly	64.3	56.2	47.1	41	8.73
gust	64.1	55.5	46.8	40	2.79
ptember	59.0	50.9	42.8	32	2.39
tober	49.2	41.6	34.0	19	2.16
vember	38.5	31.9	25.8	6	3.30
cember	34.5	28.8	23.9	-4	2.33
nual	47.3	39.4	31.6	-4	34.91

Results and Discussion

Vegetative bud growth began in early June 1969; d opening and active elongation began on June 5. Pearson (1931) indicated old trees opened buds om June 20-30 (table 2), about 5 to 15 days later an we observed for young trees. Fritts (1969) reported young bristlecone pines in the White Mountains of California initiated growth on June 25 in 1962, June 14 in 1963, and June 24 in 1964. Fritts also found that bud growth began 4 to 17 days later on old trees than on young trees. These differences are of the same magnitude as those observed in the San Francisco Peaks.

The dark purple female and orange to red colored male flower buds were fully developed by July 22, 1969. Pollen shedding started about the same time female flower buds opened, and pollen dissemination lasted approximately 5 days.

A few cones were opening on September 27, 1969, with greater numbers by October 2. Most of the cones were open by October 10. Pearson (1931) reported that seeds mature from September 20 to October 10. Our earliest cone collections on September 24 yielded some mature seeds.

Cone specific gravity dropped most rapidly between September 24-25 and September 27. During this 4-day period, average specific gravity of the cones dropped from 0.83 to 0.68. By October 2, the average specific gravity was 0.65. Cones started to open when the specific gravity dropped to 0.62 and were completely open at 0.57. Since cones started to open when the specific gravity reached 0.62, cone collections after October 5 in 1968 would have resulted in low seed yields. Cone opening started at the same specific gravity as that determined for sugar and ponderosa pine in California (Schubert 1955).

Table 2.--Phenologic data for bristlecone pine in the San Francisco Peaks area, 1918-23 (Pearson 1931) and 1969

Plant activity	1918-23	1969
Vegetative buds swelling	June 1-20	June 1
Vegetative buds elongating or opening	June 20-30	June 15
Shoots making rapid growth	July 1-30	--
Male buds appearing	July 1-10	--
Female and male buds mature	--	July 22
Pollen falling	July 20-Aug 20	July 22-27
Cones full grown	Sept 10-20	--
Seeds mature	Sept 20-Oct 10	Sept 24-Oct 2
Cones opening	--	Sept 27-Oct 10
Leaves falling	Oct 1-30	--
Period of active growth	June 20-Sept 20	--

Cones with the lowest specific gravity opened fastest. Those collected on September 24-25 with an average specific gravity of 0.83 required over 4 days to open compared to only 2 days for those collected on September 27 and October 2 when specific gravity averaged between 0.65 and 0.68. The linear regression of specific gravity times days to open had a correlation coefficient (r) of 0.87 (table 3). Cones with a specific gravity over 0.92 failed to open within 10 days in the growth chamber.

Bristlecone pine cones varied greatly in size (table 4). The sample of 74 cones averaged about 7 centimeters in length and nearly 3 centimeters in width. Cone shape was consistent for all sizes, as indicated by the correlation coefficient (r) c 0.96 for the linear regression of length times widt (table 3). The cones weighed about 27 grams eac or about 27 pounds per bushel. Nearly 450 c these small cones were required to fill a bushe basket (table 5). A pound bag held almost 1 cones. The collections made in 1969 average about 40 seeds per cone or 19,800 seeds pe bushel. A 100-pound bag held over 1,600 cone with an average yield of 73,100 seeds. A bush of cones yielded 452 to 464 grams of cleaned see Moisture content of extracted seeds averaged 5. percent on an ovendry-weight basis. These estimate were all based on bulk lots of cones collecte in 1969.

Table 3.--Statistics for several linear regression relationships for bristlecone pine cones and seeds from the San Francisco Peaks in Arizona

Linear regression	$\overline{X}$	$\overline{Y}$	SD X	SD Y	Intercept	Slope	r	r
Cone length × cone width (mm)	7.3	2.9	1.2	0.4	0.757	0.297	0.96	0.
Specific gravity × days for cone to open	71.3	2.8	9.2	1.7	-8.454	.157	.87	.
Specific gravity × germination	71.3	92.6	9.2	8.3	151.609	-.828	-.92	.
Specific gravity × full seeds	71.3	36.2	9.2	22.4	-36.658	1.021	.42	.
Cone length × total seeds	7.3	44.2	1.2	24.0	13.649	4.202	.21	.
Cone length × full seeds	7.3	36.2	1.2	22.4	5.859	4.164	.22	.
Total seeds × full seeds	44.2	36.2	24.0	22.4	-4.429	.918	.98	.

Table 4.--Variation in size of bristlecone pine cones in the San Francisco Peaks of Arizona

Variation	One cone							Bushel of cones
	Length		Width		Weight		Volume	
	Cm.	In.	Cm.	In.	Grams	Ounces	Cubic centimeters	Pounds
High	10.3	4.1	3.8	1.5	53	1.87	74	27.8
Low	5.1	2.0	2.2	.9	14	.49	22	26.4
Average	7.3	2.9	2.9	1.1	27	.95	40	27.1

Table 5.--Variation in cone and seed yield for bristlecone pine in the San Francisco Peaks of Arizona, 1969

Product and variation	Quantity of cones and seeds in relation to--					
	Seed weight			Cone weight		
	Gram	Ounce	Pound	Pound	Bushel	100-pound bag
	- - - - - - - - - - - - - - - - -		Number	- - - - - - - - - - - - - - - - -		
Cones--						
High	1.03	29.2	468	17.0	460	1,697
Low	.93	26.3	421	16.1	436	1,609
Average	.98	27.7	443	16.5	448	1,653
Seeds--						
High	42.1	1,194	19,100	751	20,400	75,100
Low	38.7	1,097	17,500	722	19,300	72,200
Average	40.0	1,134	18,100	731	19,800	73,100

Seed yields from cones collected in 1968 were similar to those collected in 1969 (table 6). An average cone had 44 seeds, of which 8 were empty. The most seeds removed from a single cone was 105; the least was 10. The cone with the most seeds also had the greatest number of sound seeds—93. Based on these estimates, one could expect about 16,000 good seeds per bushel of cones or 60,000 per 100-pound bag.

We found a very strong correlation between total seeds and full seeds per cone, as indicated by the correlation coefficient of 0.98 (table 3). We found very little correlation, however, between number of sound seeds and either specific gravity or cone length. Therefore, even small cones can be expected to have good seed yields.

Specific gravity—an index of cone dryness and maturity—did account for 91 percent of the variability in seed germination, however (table 3, fig. 2). Cones with a specific gravity of 0.75 or less when collected had the most viable seeds—over 90 percent of their sound seeds germinated. Furthermore, this mature seed was the first to germinate. Most of this fast germinating seed came from cone collections made on September 27 and October 2 (fig. 3).

Bristlecone pine seeds showed no evidence of dormancy (fig. 3). About 75 percent of the seeds germinated within 8 days. Seeds from the last two collections germinated faster than those from the first collection. No stratification or other seed treatments were tested to determine if germination could have been speeded up. Generally, stratification has been found helpful for most conifers in the "white-pine" group.

Table 6.--Variation in number of full and empty seeds for bristlecone pine in the San Francisco Peaks of Arizona, 1968

Seed quality class	Quantity of cones		
	One	Bushel	100 pounds
	- - -	Number	- - -
Full--			
High	93	16,640	61,400
Low	7	15,770	58,210
Average	36	16,210	59,810
Empty--			
High	18	3,710	13,680
Low	0	3,510	12,970
Average	8	3,610	13,320
Total--			
High	105	20,350	75,080
Low	10	19,290	71,180
Average	44	19,820	73,130

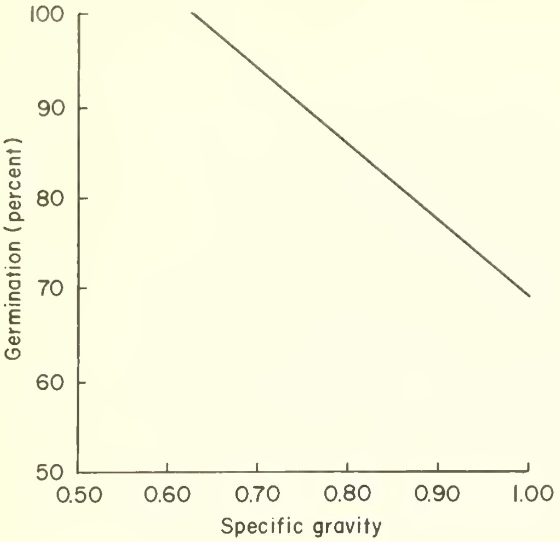

Figure 2.--Cone specific gravity as an index to seed germination for bristlecone pine from the San Francisco Peaks in Arizona.

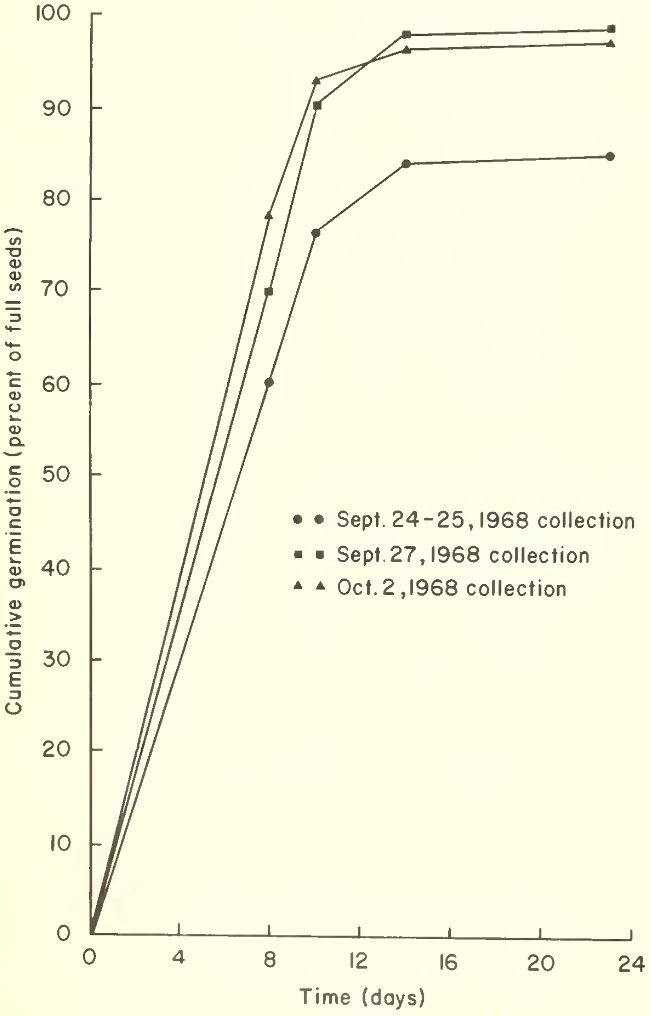

Figure 3.--Cumulative seed germination by cone collection dates for bristlecone pine from the San Francisco Peaks in Arizona.

Summary

This information should help anyone time his visit to a stand of bristlecone pines with the occurrence of a particular growth event. Basic cone and seed data are also presented.

The principal results of the study are:

1. Vegetative buds of bristlecone pine started swelling in early June, with bud-bursting and active elongation in mid-June. Flower buds matured around July 22, and pollen was released for about 5 days. Seeds matured from September 24 to October 2, and were released from September 27 to October 10.
2. Seed viability is strongly correlated with cone specific gravity. Cones yielded the most viable seeds if they were collected after their specific gravity had dropped to 0.75 or less. Most cones began to open when their specific gravity reached 0.62, and were completely open at 0.57. For these reasons, cones should be collected when their specific gravity falls below 0.75.
3. Bristlecone pine cones are uniform in shape, but vary greatly in size, with an average length of about 7 centimeters and width of 3 centimeters. About 17 cones are required to make a pound, and about 27 pounds of cones fill a bushel basket. The number of seeds per cone ranges from 10 to 105, but averages 40. A bushel of cones yields about 1 pound of seed (452-464 grams). There are about 16,000 sound seeds per bushel of cones.
4. The number of sound seeds per cone is strongly correlated with total seeds. There is little correlation, however, between number of sound seeds and either specific gravity or cone length. Therefore, it appears worthwhile to collect small cones in addition to large ones.
5. Although no particular stratification treatments were tested, there did not appear to be any requirement for such a treatment.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 181

ST SERVICE
DEPARTMENT OF AGRICULTURE

MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Measuring Illumination Within Snow Cover with Cadmium Sulfide Photo Resistors

James D. Bergen[1]

Light-sensitive cadmium sulfide resistors can measure the downward flux of sunlight in the snow cover. When the variation of sensor response and the absorptivity of ice are considered together with the approximate distribution of energy in the solar spectrum, the variation of cell resistance (R) is estimated by

$$4.55/RE^{.925} = 2.1\,X^{.925} + X^{3.27}$$

where (E) is the total incident radiation at the snow surface and (X) is the average attenuation ratio for radiation between 0.5μ and 0.7μ. The last term becomes negligible for values of X<0.3.

KEY WORDS: Solar radiation, sunlight, light scattering, photometers, turbidimetry.

The attenuation of light within a snow cover ne of the few nondestructive physical measure- nts which can be made on natural snow. iough ideally such measurements would be made i a monochromatic light source, the boundary blems for the case of a finite beam of light are iplex and largely unexplored, compared to the pler situation of uniform natural illumination.

In the field, attenuation measurements have ally been made by inserting a selenium light- er, often equipped with standard photographic rs, into the snow cover from the wall of a ich. The disturbing effect of the trench wall cts accuracy, however, and prevents the study he undisturbed evolution of a single volume of w. While equivalent results may be obtained by a series of trench measurements in a uniform snowfield of great extent, such snow covers are uncommon outside the polar regions.

To measure light attenuation in a restricted volume of snow and its variation with time, a sensor was needed that could be deposited in the snow cover at intervals during its formation (Swanson 1968). Such a sensor would cause minimal disturbance of the snow cover during and between measurements. There are three main requirements for such a device:

First, it must be small and light enough to avoid distortion of the natural settlement and movement of heat and water vapor and radiation through the snow cover.

Secondly, it must be insensitive to the large variations in local snow temperature in a mountain snow cover.

Thirdly, the sensor must be inexpensive, since many are required for meaningful measurements in snow cover consisting of as many as 15 deposition layers.

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[1] *Meteorologist, Rocky Mountain Forest and ge Experiment Station, with central head- rters maintained at Fort Collins, in cooper- on with Colorado State University.*

The instrument finally chosen was a cadmium sulfide photosensitive resistor, sold as the (B8-73103) by Ferrocube Corporation.[2] This CdS cell is a compact cylinder of 6 mm. radius and 6 mm. length. The active face of the cell is a matrix of CdS enclosed by a glass envelope.

The current (i) through the cell at any given intensity and wave length (λ) of incident radiation is approximately proportional to the applied voltage (e) for voltages of 1 to 20 v. The cell thus may be regarded as following Ohms law,

$$i = e/R \tag{1}$$

with an effective resistance (R) dependent on the incident illumination. For light of wavelength 0.68μ

$$R = 0.7634\ I^{-0.925} \tag{2}$$

where I is the intensity of the radiation in cal cm^{-2}min^{-1} and R is in ohms.

The relative variation of the current induced by the incident radiation at a given cell voltage with (λ) is shown in figure 1, where the ordinate (R_λ) is the cell current at wavelength (λ) scaled by the corresponding current at a wavelength 0.68μ. Thus

$$d(\frac{1}{R}) = 1.31 R_\lambda (I'_\lambda)^{.925}\ d\lambda$$

where I'_λ is the incident intensity of monochromc radiation at wavelength λ in the langleys min

Below saturation values of incident radiati (about 1 langley min^{-1}), the currents produced the various components of heterochromatic radiati are independent of each other, and

$$i/e = 1.31 \int_\lambda R_\lambda\ I^{.925} d\lambda$$

where I is the spectral energy density of the cident radiation at λ.

When these instruments are used to measu the natural illumination within a snow cover, t heterochromatic radiation is the solar energy cident on the snow surface and its modified fo at the positions of the photoresistors. If the spect density of this radiation may be expressed $EI_\lambda d\lambda$, where E is the total incident solar energ the relation (3) becomes

$$1/R = 1.31\ E^{.925} \int_\lambda R_\lambda\ \ I_\lambda{}^{.925}\ \ d\lambda$$

Even at the snow surface, there are no gene expressions for I_λ. The form of the solar spectru varies both with solar altitude, general airmc characteristics, clouds, and the elevation of the si Thus, the integral above cannot be evaluated detail for the general situation. Not only is t surface spectrum relatively indeterminate, but tl change in form of the spectrum with distance in the pack depends on the optical properties of t snow, which vary considerably between and with snow covers.

For a uniform snow layer with an isotropic flectivity (Dunkle and Bevans 1956), the downwa flux ($I_{\lambda z}$) of diffuse monochromatic radiation of wavelength at a depth z is

$$I_{\lambda z} = I_{\lambda o} \exp\ [-\beta_\lambda\ \ z]$$

and

$$\beta_\lambda = (k_\lambda^2 + 2k_\lambda r_\lambda)^{1/2}$$

where $I_{\lambda o}$ is the flux density at the surface.

r_λ is assumed to be proportional to the r flectivity of ice at wavelength (λ), and (k_λ) is pr portional to the volume absorptivity of ice at th wavelength, as shown in figure 2, from measur ments by Sauberer (Mantis 1951).

The relation between the absorption coefficier of a material in a dispersed phase and the cc responding constants in its nondispersed state still a matter of hypothesis, largely because of tl difficulty in separating true absorption from sc tering in most experiments. Thus, for blue lig

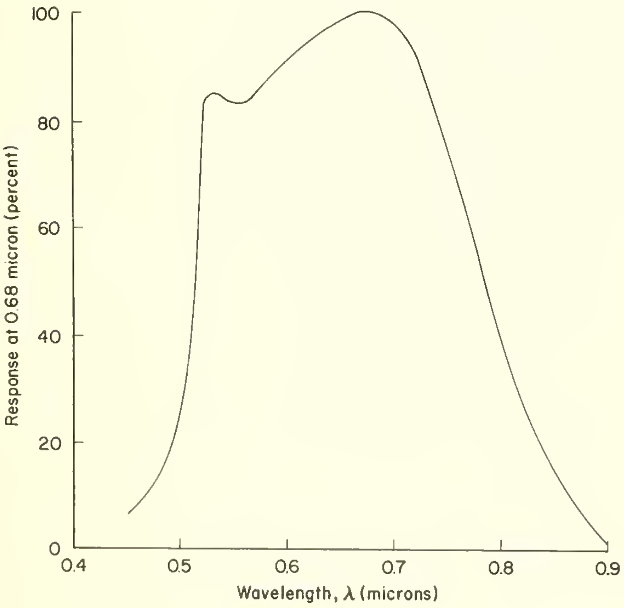

Figure 1.--Spectral response curve for the cadmium sulfide photoresistor relative to λ of 0.68 micron.

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[2] *Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

ith λ at about 0.42μ, Liljequist (1956) computed, om separate measurements of the upward and ownward flux of radiation, a volume absorptivity f 0.028 cm^{-1} as compared with the value of 0.004 m^{-1} indicated by the measurements of Sauberer Mantis 1951). Measurements by Lathrop (1966) ndicate that the ratio of k_λ for the dispersed ma-erial to that of the solid material is a function of rain size and material absorptivity; the ratio de-reases as their product increases. Measured values f the ratio computed on a unit mass basis range rom 8 to 3. Explaining the variation, Lathrop ssumes that the illumination field varies appreciably n a distance corresponding to the average path ength between reflections. For snow with a grain ize of about 1 mm. at λ = 0.4μ, his model yields ratio of the absorption coefficients of about 10, which is not far from Liljequist's ratio of 7.0. athrop's model seems most appropriate to a medium where the particles are large, discrete lumps. While hese and other similar results may be open to uestion, the results of the calculations to be made elow will not be affected if we accept either the bsorptivity of solid ice, or ten times that value s an upper bound for k_λ at the same wavelength or diffuse radiation.

While a number of values have been measured nd used for the reflectivity of ice at normal in-idence (Mantis 1951), in no case has any appre-iable variation with wavelength through the region .4μ to 1.0μ been detected. Measured and cal-ulated values range from 0.018 to 0.56.

An expansion of equation (6) above in a bi-omial series is

$$= (2k_\lambda r)^{1/2} + \frac{(2k_\lambda r)^{-1/2}}{2} k_\lambda - \frac{(2k_\lambda r)^{-3/2}}{8} + \ . \ . \ .$$

or λ less than 0.7μ, and assuming that k_λ is less han 10^{-2} cm^{-1} and that r is at least as great as or a single ice-air interface, the last two terms are egligible to within a 10 percent approximation. hus for any index wavelength λ_i in this region:

$$\beta_\lambda \simeq (2k_{\lambda i} r)^{1/2} \qquad (7)$$

similar calculation indicates that only the second erm becomes appreciable relative to the first over he entire range of sensor response; that is

$$\beta_\lambda \simeq (2k_\lambda r)^{1/2} + \frac{k_\lambda^{3/2}}{2} (2r)^{-1/2} \qquad (8)$$

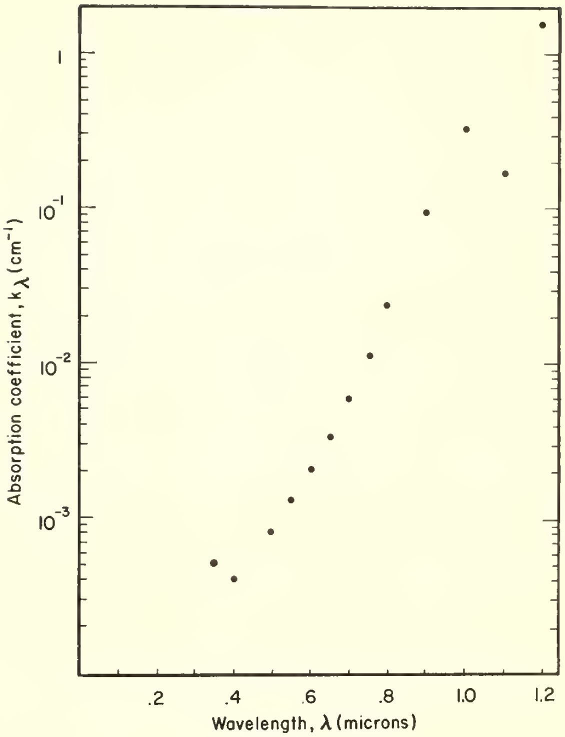

Figure 2.--Variation of the absorption co-efficient of ice with the wavelength of the incident radiation.

By relations (5), (7), and (8)

$$\frac{I_\lambda}{I_{\lambda o}} = X^\alpha \exp\ [(\ell n X)^\delta z] \qquad (9)$$

where

$$\delta = (2/k_\lambda^3\ k_{\lambda i})^{1/2}$$

$$\alpha = (k_\lambda\ /k_{\lambda_i})^{1/2}$$

and

$$X = I_{\lambda_i z}/I_{\lambda_i o}$$

Computation shows that the exponential factor in equation (9) varies by less than 1 percent from unity over the entire range of sensitivity for snow depths of up to 3 m. and porosities from 10 to 90 percent, if k_λ is bounded as previously assumed. Thus the expression for the cell resistance becomes essentially

$$\frac{1}{R} = 1.31E^{.925} \int_\lambda R_\lambda\ (I_{\lambda_i} X^\alpha)^{.925}\ d\lambda \qquad (10)$$

Equation (10) can be evaluated by dividing the spectral response curve into two regions, a "short" wave band from $\lambda = 0.5$ to 0.7μ centered at $\lambda = 0.6\mu$, which will be used as the index wavelength (λ_i), and a "long" wave band from $\lambda = 0.7\mu$ to $\lambda = 0.9\mu$ centered at $\lambda = 0.8\mu$. α depends only on the ratio of the absorption coefficients of ice at $\lambda = 0.6\mu$ and $\lambda = 0.8\mu$; computation from figure 3 yields:

$$\alpha = 3.54$$

If we approximate (I_λ) for these intervals from the solar spectral data for airmass of unity based on the measurements of Fowler and given in the Smithsonian tables (List 1951), and evaluate the band average values of R_λ from figure 3 equation (11) becomes

$$\frac{4.55}{RE^{.925}} = 2.1X^{.925} + X^{3.27} \qquad (11)$$

The variation of the righthand side of equation (11) for $X > 10^3$ is shown in figure 3. As may be seen, the last term becomes less than 1 percent of the first for values of X less than 0.3.

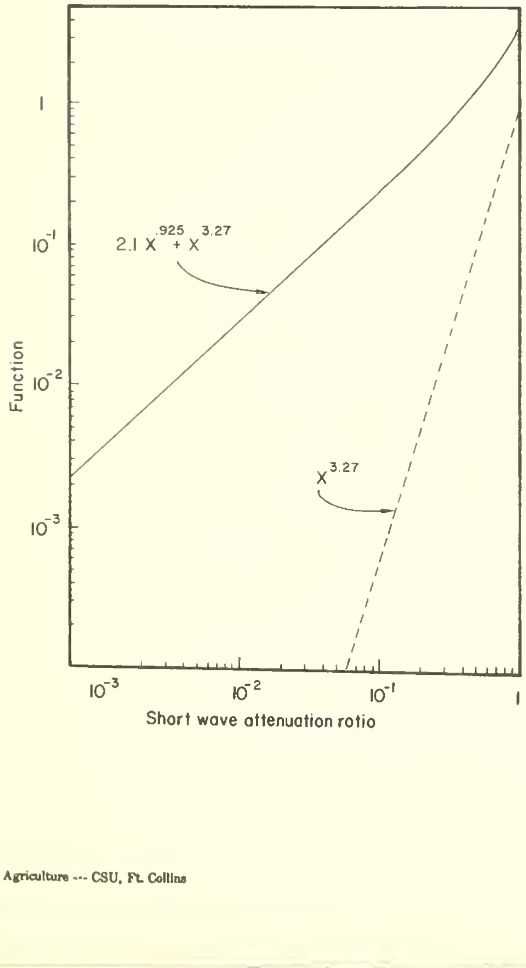

Figure 3.--Variation of two functions of the shortwave attenuation ratio.

For E in the vicinity of 1.5 langley min^{-1}, this would imply that the last term vanishes for CdS cell resistances greater than about 300 ohms. For these conditions, the incident energy E_z and the attenuation between two levels may be estimated directly from the measured resistances as

$$I_\lambda = 5.78\ (R)^{-1.081}$$

For lower cell resistances, however, some independent estimate of E would be needed, such as that furnished by a radiometer at the surface.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 182

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Effects of Watering Treatments on Germination, Survival, and Growth of Engelmann Spruce:

A Greenhouse Study

Robert R. Alexander
and
Daniel L. Noble[1]

Germination increased as the amount of water received increased from none to 1.5 inches per month. The distribution of water influenced total germination only when the amount received was 1.0 inch or less. There was no significant survival after 24 weeks until 1.0 or more inches of water was received monthly, applied at intervals throughout the month, whereas few seedlings survived until 2.0 inches of water was received monthly in a single watering. Top height, root elongation, and total plant dry weight were not significantly related to watering treatments.

KEY WORDS: Picea engelmannii, plant water relations, plant physiology, seed germination.

Natural reproduction of Engelmann spruce (*Picea gelmannii* Parry) after clearcutting has been highly riable in the Rocky Mountains. Regeneration ccess is often related to weather factors (Roe al. 1970).

One weather factor that obviously affects reneration success is the amount and distribution precipitation which varies considerably during the owing season and from year to year. If precipitan is low or irregular following snowmelt in late y and June, exposed soil surfaces are rapidly ed out and heated to high temperatures during riods of clear weather. Few seeds can imbibe ficient water to germinate and most new seedlings e killed by either drought or stem girdle (Day 63, 1964; Roe et al. 1970). On the other hand, germination is delayed until after late summer rains begin, seedlings are unable to harden off properly before the onset of cold weather (Ronco 1967).

The studies reported here were made under controlled greenhouse conditions in 1967 and 1968 to supplement field observations of spruce regeneration. Germination, initial survival, and early growth of spruce were compared under watering treatments selected to represent the precipitation patterns most likely to be encountered on the Fraser Experimental Forest in central Colorado.[2]

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[1] *Principal Silviculturist and Forestry search Technician, Rocky Mountain Forest and nge Experiment Station, with central headarters maintained at Fort Collins, in coopation with Colorado State University.*

[2] *U. S. Weather Bureau records for a 35-year period (1931-66) from Fraser, Colorado--approximately 5 air miles from the study areas--at 8,500 feet elevation, indicate that average precipitation from June through October varies from 1.75 inches in July to 1.00 inch in October, with a range of 0.50 to 2.50 inches covering most years (U. S. Weather Bureau 1935-66). Monthly precipitation is most likely to fall in either several small storms of 0.25 inch or less, or in one or two larger storms.*

Methods and Materials

Seed sources.—Engelmann spruce seeds collected in 1965 on the Williams Fork drainage of the Arapaho National Forest, and in 1966 on the Fool Creek drainage of the Fraser Experimental Forest, were used in 1967 and 1968, respectively. Both lots of seed were collected at about 10,000 feet elevation. Average laboratory germination was 55 and 60 percent, respectively.

Soil and seeding.—Forest soil from 10,500 feet elevation on the Fraser Experimental Forest was used. This fine, sandy loam of the Darling series—developed in place under a mature spruce-fir stand from gneisses and schists (Retzer 1962)—was screened through 4-mesh hardware cloth in the field and thoroughly mixed before potting. Moisture capacities at 1/3 and 15 atmospheres, determined in the laboratory, were approximately 15 and 31 percent, respectively.

Pots were soaked twice daily for 3 days before sowing. Twenty seeds were then carefully broadcast on the surface of each pot. All pots were then soaked again to insure that soil moisture was near field capacity before watering treatments were begun. A total of 75 pots, 7 inches deep and 6 inches in diameter, were prepared each year.

Experimental design and treatments.—The experiments were a randomized block design with water at five levels, replicated three times. Because of the arrangement of available space in the greenhouse, pots within replications were arranged in 5 rows of 5 pots. Each row was randomly assigned one of the following watering treatments: none, 0.5, 1.0, 1.5, and 2.0 inches monthly. In 1967, 0.25 inch of water was applied at each watering. The number and interval between waterings each month was determined by the assigned treatment. In 1968, all water was applied at the assigned level once a month.

Greenhouse environment.—Environment in the greenhouse at Fort Collins, Colorado, was maintained as closely as possible to average field conditions during the growing season at 10,500 feet elevation on the Fraser Experimental Forest. Air temperatures were 70° F. (day) and 40° F. (night). The photoperiod was 16 hours of natural and artificial light. The transition period of temperature changes coincided with light changes. Relative humidity wa varied from 20 to 30 percent (day) to 70 to 8 percent (night).

The high light intensity at 10,500 feet elevation- up to 16,000 foot-candles (ft.-c.)—associated wit mortality of open-grown seedlings in the field, coul not be approximated in the greenhouse. The no mally lower light intensity at 5,000 feet elevatio was further reduced by the greenhouse glass, s that light intensity inside the greenhouse varied fro 3,000 ft.-c. on cloudy days to about 5,000 ft.- on clear days.

Measurements and analyses.—Number of ge minating seeds, number of surviving seedlings, an cause of mortality were recorded biweekly. At th end of 24 weeks, the soil was carefully washe from the roots of all live seedlings, and the to height and root length measured to the neare millimeter. The tissue was then ovendried for 2 hours at 100° C. and weighed to the closest 0. milligram.

Germination and survival were expressed as percent of the number of seeds sown per pot; to height, root length, and total seedling dry weig were weighted pot means. Differences due to trea ment were tested for significance by analyses variance with arc-sin transformations for percentag data. The means of significant main effects we tested by Tukey's Test.

Results

Germination.—Total germination increased from 27 to 48 percent in 1967 and from 12 45 percent in 1968—as the amount of water r ceived increased from none to 1.5 inches per mont Additional water did not significantly improve tot germination (fig. 1).

The distribution of water influenced total ge mination only when the amount received each mon was 1.0 inch or less. Nearly twice as many see lings emerged in 1967 when water was applied predetermined intervals during the month as 1968 when the same amount of water was applie only once a month (fig. 1).

Length of germination period.—The length of tim over which seedlings emerged was influenced mo by the distribution of water than the amount r ceived. In 1967, most seeds that germinated h emerged by the 28th day in all treatments (fig.

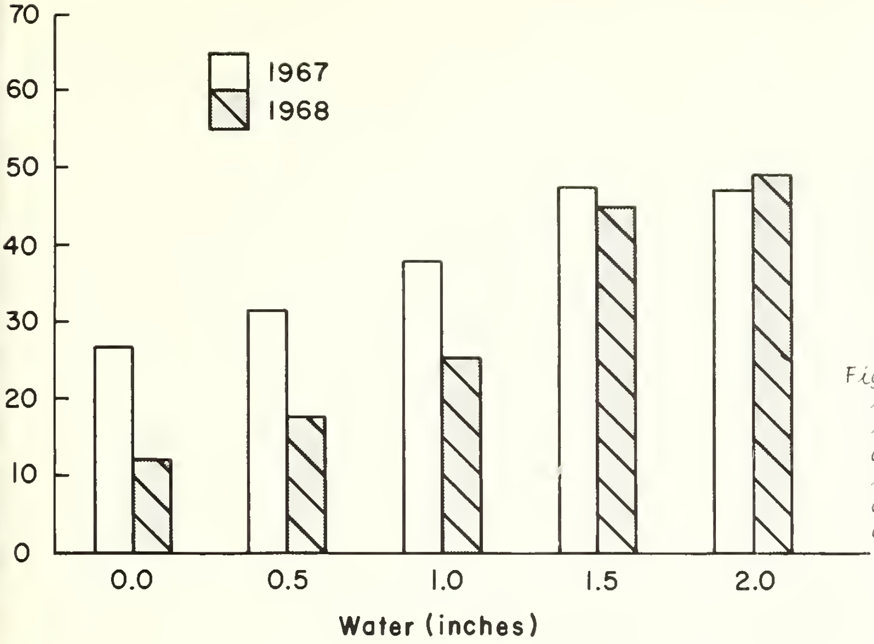

Figure 1.--Total germination in relation to watering treatments in 1967 (water applied at predetermined intervals during the month), and in 1968 (water applied only once a month).

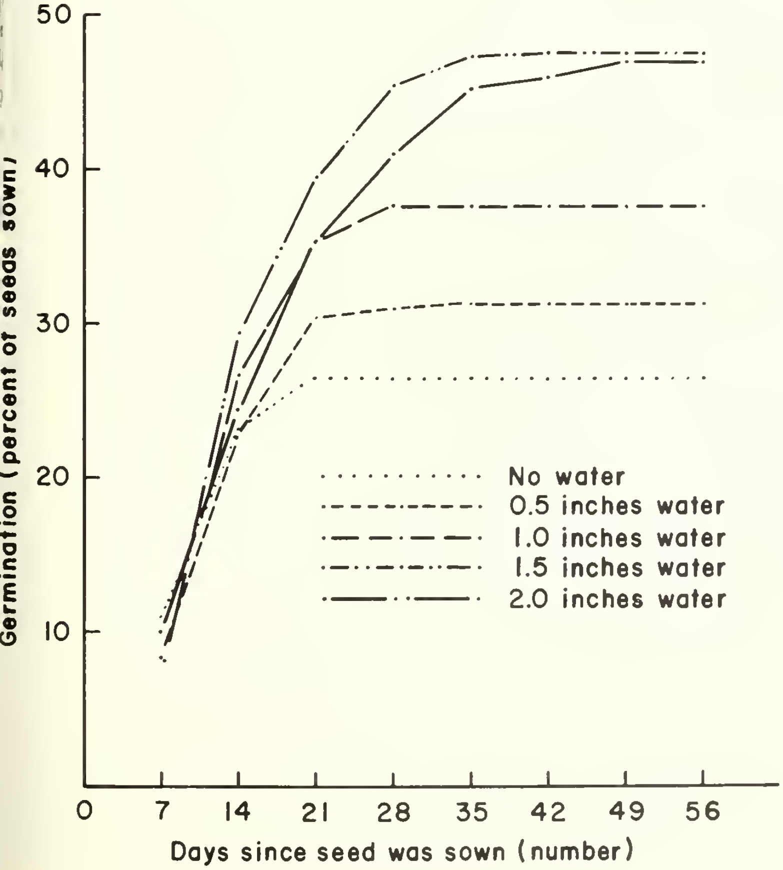

Figure 2.--Length of germination period in relation to watering treatments in 1967 (water applied at predetermined intervals during the month).

Germination in the unwatered and 0.5-inch treatments was completed by the end of the second week in 1968, but in the treatments receiving 1.0 or more inches of water, seedlings continued to emerge for as long as 3 months (fig. 3).

Seedling survival.—Number of seedlings surviving after 24 weeks in 1967 and 1968 was related to both amount and distribution of water received. When water was applied at predetermined intervals in 1967, 1.0 inch monthly was required to sustain any significant survival (fig. 4). Survival was increased with an increase in water received to 1.5 inches, but more water did not significantly improve seedling survival. In contrast, few seedlings survived when water was applied only once a month in 1968, until 2.0 inches were received. Even then survival was less than in the 1.0-inch treatment in 1967 (fig. 4).

The effect of the distribution of water on survival was most apparent in the 1.5- and 2.0-inch treatments, where total germination in 1967 and 1968 was comparable. After 24 weeks, 80 to 85 percent of the seedlings that emerged were alive in 1967, whereas only 10 to 30 perce the seedlings that emerged in 1968 survived.

Causes and time of mortality.—In 1967, dam off shortly after emergence was the prin cause of mortality in treatments receiving 1 more inches of water (table 1). Most losses other causes in those treatments occurred d the first 6 weeks after seeds were sown. Dro was responsible for most mortality in the unwa and 0.5-inch treatments, and there was no signif survival after 6 and 18 weeks, respectively. S losses occurred when the radicle emerged the seedcoat and did not develop further, e because the seeds could not imbibe sufficient w for the radicle to become rooted or the seed not have enough germinative vigor to com establishment, but mortality from failure to e lish was important only in the unwatered, 1.5-, 2.0-inch treatments (table 1).

Mortality in 1968 resulted largely from drou regardless of the amount of water received.

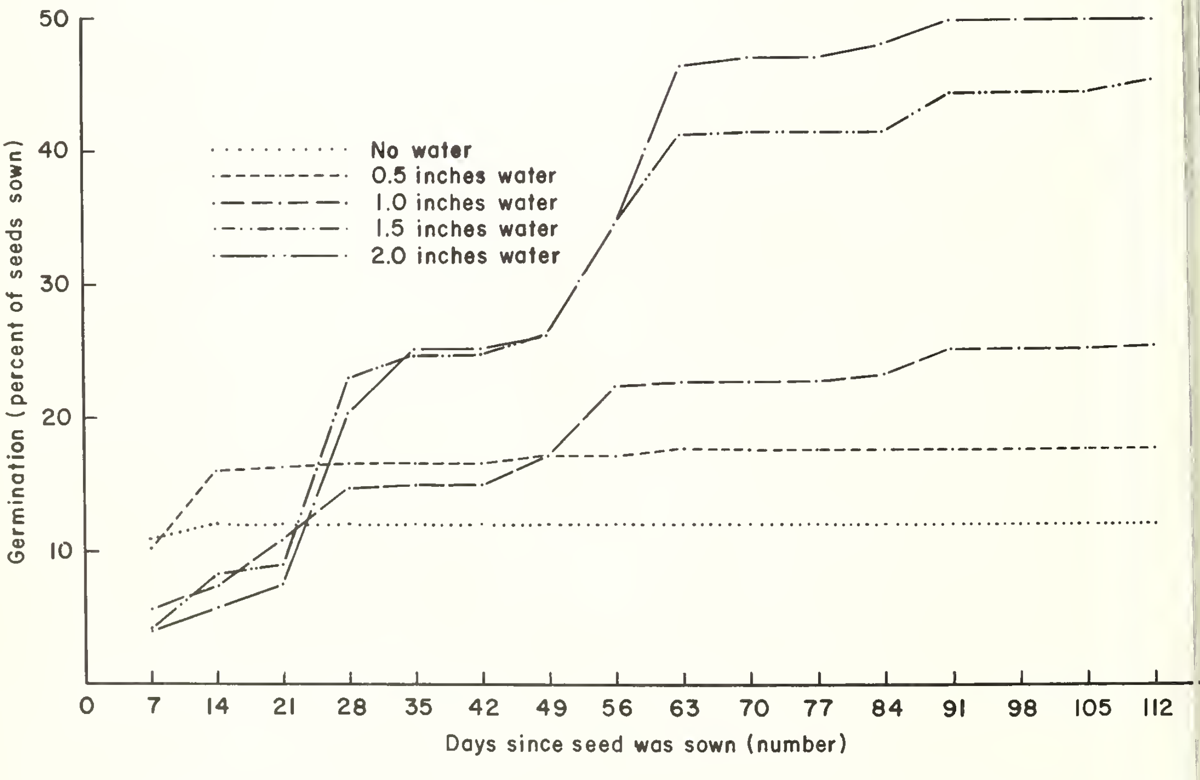

Figure 3.--Length of germination period in relation to watering treatments in 1968 (water appl only once a month).

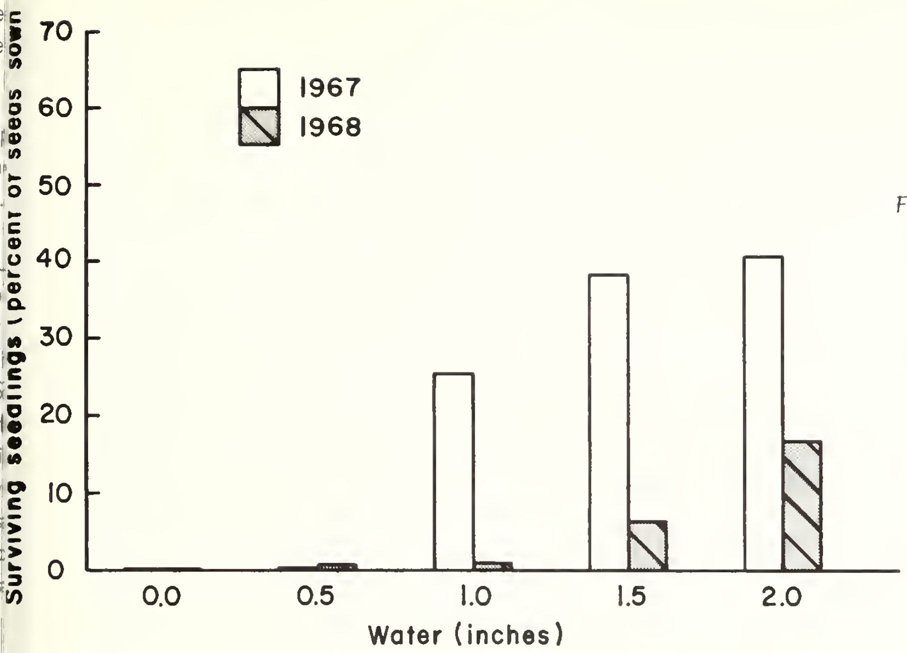

Figure 4.--Seedling survival after 24 weeks in relation to watering treatments in 1967 (water applied at predetermined intervals during the month), and in 1968 (water applied only once a month).

other losses were caused by failure to establish table 1). Nearly all seedlings in the unwatered, 0.5-, and 1.0-inch treatments had died after 28, 56, and 63 days, respectively; and mortality substantially reduced seedling numbers in the 1.5- and 2.0-inch treatments for as long as 3 months after seedlings began to emerge.

Seedling growth.—Top height, root elongation, and total plant dry weight were not significantly related to amount or distribution of water. Mean top height, root length, and seedling dry weight after 24 weeks, averaged over all treatments and years, was 1.04 inches, 7.01 inches, and 30.5 grams, respectively.

Table 1.--Percent total mortality, by cause, of greenhouse-sown Engelmann spruce seedlings watered at predetermined intervals during the month (1967) compared with those watered once a month (1968)

Monthly water treatment (Inches)	Drought		Damping-off		Failure to establish		Other causes	
	1967	1968	1967	1968	1967	1968	1967	1968
					Percent			
0.0	60.0	63.9	12.5	0	26.3	36.1	1.2	0
0.5	81.7	70.6	10.8	0	6.4	29.4	1.1	0
1.0	37.8	54.8	43.3	0	10.8	45.2	8.1	0
1.5	14.8	76.7	59.3	6.0	22.2	16.4	3.7	0.9
2.0	10.5	62.9	52.6	11.3	31.6	24.8	5.3	1.0

Discussion and Conclusions

The environment maintained in the greenhouse was more favorable to seedling establishment and growth than that likely to occur often in the field. It is difficult, therefore, to extrapolate results obtained in the greenhouse to the field. Nevertheless, some inferences can be drawn from these studies, coupled with observations in the field, concerning the effects of amount and distribution of precipitation on germination and first-year seedling survival and growth.

When monthly precipitation during the summer is 1 inch or less, more seedlings emerge with frequent showers than with one or two larger storms (fig. 1). When summer rainfall averages 1.0 inch or more monthly, total germination is completed in a relatively short time with frequent showers, whereas seedlings emerge throughout the growing season if precipitation occurs in only one or two storms (figs. 2 and 3).

At least 1 inch of favorably distributed precipitation is needed monthly before seedlings survive in significant numbers. With this precipitation pattern, however, seedling survival is not likely to be greatly increased with more than 1.5 inches of monthly rainfall.[3] On the other hand, few seedlings will survive with less than 2.0 inches of rainfall monthly when precipitation occurs only infrequently.

Size and biomass of spruce seedlings that survive the first growing season do not appear to be related to the amount or distribution of precipitation. However, this may not hold for field-grown seedlings since average top height and root length of seedlings grown for 24 weeks in the greenhouse were about double that of 4-month-old seedlings growing on mineral soil seedbeds on the Fraser Experimental Forest.

In this discussion precipitation has been considered as an independent variable. However, many other weather and environmental factors and their interactions also affect regeneration success, and must be evaluated before the effectiveness of any one factor such as precipitation can be fully analyzed.

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[3] *The chances of 1.0 or more inches of precipitation favorably distributed during the growing season on the Fraser Experimental Forest are estimated at about 3 out of 4 years in the month of July, 2 out of 4 years in June and August, and 1 out of 4 years in September and October (U. S. Weather Bureau 1931-66).*

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 183

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Clearing an Alligator Juniper Watershed with Saws and Chemicals: A Cost Analysis

Robert L. Miller[1]

Manpower, equipment, materials, and vehicle input data were analyzed for seven component jobs involved in an experimental conversion of an alligator juniper watershed to herbaceous cover. Total operational cost was $45.02 per acre. Analysis indicates that costs may be reduced substantially in an operational program through improved organization, changing prescriptions and techniques, and further cost studies.

KEY WORDS: Forest conversion, forestry business economics, production functions, Juniperus deppeana, watershed management.

Land managers in the Southwest need new anagement practices to meet rising demands for ater and other products of the land. Cost data e needed for use in designing and evaluating actices, and to estimate budgets for possible treatent programs. Finding ways to reduce costs is pecially important because of the potential for proving efficiency in large-scale treatment ograms.

A series of cost studies has been carried out in nnection with experimental watershed treatments the Beaver Creek Watershed Evaluation Project orley 1965). Specific objectives of these cost studies are to: (1) summarize and interpret experimental treatment costs in operational terms; (2) indicate where and how costs can most likely be reduced; and (3) develop criteria for identifying areas and conditions of high and low treatment costs for planning and evaluating treatment alternatives.

This report presents cost data and analyses for an actual case of converting a 100-acre alligator juniper (Juniperus deppeana Steud.) watershed on Beaver Creek entirely to herbaceous cover (fig. 1). The techniques used were experimental, and were selected to minimize disturbance of the soil surface, and thus increase the possibility of additional runoff. Earlier studies on the Beaver Creek Pilot Watersheds indicated that disturbances to the soil caused by use of large tractors and cables to uproot juniper trees may inhibit effective runoff from treated watersheds (Brown 1965, 1969).

The use of saws and chemicals instead of heavy equipment for juniper eradication was experimental. Whether this treatment will be effective in increasing

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[1] *Associate Economist, Rocky Mountain For- t and Range Experiment Station, with central adquarters maintained at Fort Collins, in operation with Colorado State University. ller was located at Tucson, in cooperation th the University of Arizona; he is now with e Department of Forestry, Oklahoma State iversity, Stillwater.*

Figure 1.--Part of the watershed after the felling operation.

water yields will not be known until evaluation studies now underway have been completed. The cost analyses presented here provide a basis for comparing costs of this unusual treatment with the more common alternatives, and they illustrate the use of cost analysis as a means of identifying opportunities for reducing costs of land treatments.

Treatment Inputs

The treatment was first separated into component jobs (fig. 2) in the manner previously indicated by Worley et al. (1965). Treatment inputs were classified as supervision, labor, equipment, materials, and vehicle use (table 1). Overhead costs were not considered.

The operation was highly labor-intensive (table 2); the requirement of about 10 man-hours per acre accounted for 57 percent of total costs (table 3). For possible labor cost reductions, three jobs—felling large trees, felling small trees, and spraying juniper stumps and seedlings—need to be specially considered. They accounted for about three-fourths of total man-hours. The total requirement of 6 man-hours per acre to fell trees should be co pared to possible alternative techniques of individu tree burning or bulldozing. A study by Cotr and Jameson (1959) indicates that either of the techniques would require less than 1 man-hou

Herbicide applications were unavoidably labo ous and repetitive because of chemical specifici different seasonal requirements for the three spec of vegetation, and the need for follow-up treatme of sprouts and skips (table 2).

Transportation of men, materials, and equipme to and from the watershed involved five vehic and 1,655 vehicle miles. Distance between t watershed and headquarters was 17 miles. Tra time involved 1 hour per man per day, or a to of 161.5 man-hours for all workers and supervis

Input Costs

The total treatment cost of $38.57 per a (table 3) is high compared to estimated costs about $25 per acre for alternative methods

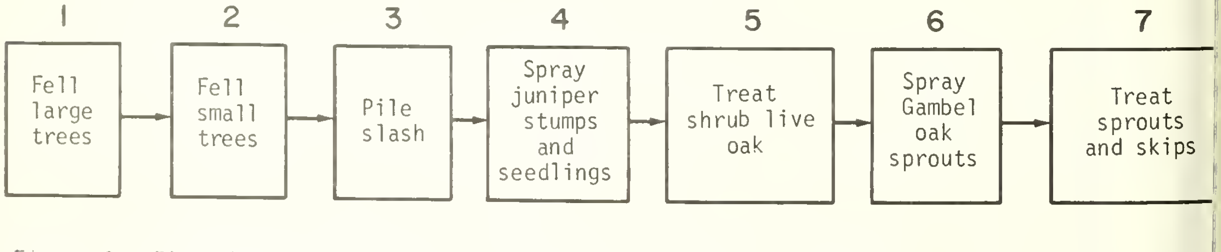

Figure 2.--Flow chart of component jobs and general order of operations. Jobs 4, 5, and 7 are interdependent with respect to costs, even though conducted separately.

Table 1.--Resources and cost rates applied in full-crew operations

Input resource	Number	Rate
Personnel (on first 5 jobs)		
Superintendent	1	$ 3.10 per hour
Foreman	2	2.50 per hour
Sawyers	11	2.25 per hour
Sawyers	2	2.05 per hour
Labor on piling slash and applying chemicals	7	2.05 per hour
Equipment		
Vehicles	5	.09 - .31 per mile
Chain saws[1]	13	.35 per hour
Back-pack pumps	6	.04 per hour[2]
Mist blower	1	.25 per hour[2]
Materials		
Diesel oil, gallons	963	.15 per gal.
PBA (Polychlorinated benzoic acid) gallons[3]	36	7.00 per gal.
Pelleted fenuron, lb..	100	99.50 per 100 lb..
2,4,5-T ester, gallons[4]	1	5.98 per gal.
Picloram and 2,4-D concentrate, gallons[5]	60	Operational cost data not available

[1] Complete data on saws actually used were not available. The applied rate for saws is an estimate based on published data.

[2] Estimated.

[3] 2 lbs. acid equivalent per gallon; applied at rate of 12 lb. acid equivalent per 100 gallons of diesel oil, or at 0.72 lb. PBA per acre.

[4] 4 lbs. acid equivalent per gallon of solution; applied at rate of 3 gallons per 100 gallons of oil.

[5] 1 lb. picloram and 2 lb. 2,4-D per gallon; applied at rate of 3 lb. picloram and 6 lb. 2,4-D in 10 gallons of water per acre.

Table 2.--Inputs for supervision, labor, equipment, and materials for seven component jobs

Component jobs	Supervision,[1] total	Labor, total	Supervision plus labor, per acre	Equipment, per acre			Materials, per acre					
				Chain saw[2]	Back-pack pump	Mist blower	Diesel oil	PBA	2,4,5-T ester	Picloram	2,4-D	Fenuron
		- - Man-hours - -			- - Hours - -			- - Gallons - -			- - Pounds - -	
large trees	60.25	251.50	3.12	3.12	--	--	--	--	--	--	--	--
small trees	67.75	270.00	3.38	3.38	--	--	--	--	--	--	--	--
slash	7.00	121.50	1.28	--	--	--	--	--	--	--	--	--
all juniper stumps seedlings	14.00	250.00	2.64	--	2.50	--	9.40	0.36	--	--	--	--
shrub live oak	5.50	28.25	.34	--	--	--	--	--	--	--	--	1.00
Gambel oak	--	19.50	.20	--	.20	--	.22	--	0.01	--	--	--
sprouts and skips	7.00	91.00	.98	--	--	1.00	--	--	--	0.60	1.20	--
	161.50	1,031.75	11.94	6.50	2.70	1.00	9.62	.36	.01	.60	1.20	1.00

Note: "--" indicates not applicable.

[1] For regular crew operations, this consisted of superintendent and two foremen; superintendent time prorated according to pro- on of total labor time by job.

[2] Saws with 28-inch bars used on large trees; bow-bar with attached guards used on small trees (use limited to trees below 9 inches ameter); lower diameter limit in felling, about 1 inch.

in the spraying job (table 5).[4] This possibility is supported in an evaluation by the USDA Agricultural Research Service as a part of continuing studies of problems in large-scale applications of herbicides (Johnsen 1967). Treatment effectiveness, in terms of proportion of plants killed, was considerably less than normally obtained in controlled research studies. For success, it was essential to thoroughly wet the root collar of the stump at the soil surface. A substantial proportion of failures was found. General conclusions were that special care is needed in instruction, supervision, and establishment of work goals in manual operations where success depends on thoroughness and details of technique.

Table 5.--Sensitivity analysis within the juniper spraying job

Job element	Average cost per acre (1)	Standard deviation (s) (2)	Cost sensitivity index (3)
	Dollars		Percent
Supervision	$0.43	0.91	3.6
Labor	5.12	.91	43.0
Materials	3.91	1.46	52.6
Equipment	.10	.91	.8
Total	$9.56		100.0

Job elements need to be examined in detail for possible improvements in efficiency. For example, workers tried different ways to pull duff away from the stump base, but none was efficient. Development of a tool for this purpose would reduce costs significantly.

Juniper spraying and shrub live oak treatments were done by a temporary crew. It can be expected that applications will be more effective and less costly if regular crews are used.

Herbicide application alternatives.—Alternatives in the specific herbicide applications are feasible. All woody vegetation on the experimental watershed was treated to maximize conditions for producing measurable additional runoff, without regard to economic considerations. In designing an operational program, each practice should be evaluated on its merits, including the consideration of differences in plant distribution. Costs per plant will be high for vegetation in sparse stands, as in the case of Gambel and shrub live oaks on this watershed. With adequate data on yields, economic evaluation of each practice can lead to increased net benefits by identifying marginal plant densities and uneconomic practices, and by indicating ways of improving the practice.

Supervision efficiency.—The substantial portion of total man-hours involved in supervision (14 percent) is another indicator of opportunity for improving efficiency. Less supervision should be required in a continuing operation with the same crew organization. Due to the use of a sawyer in the slash piling job and unusual sawyer absences in this case, supervisors on the felling jobs operated at less than two-thirds of full capacity in terms of a constant 14-sawyer operation.

Felling cost reduction.—Data on felling times were collected for 133 trees of 15 inches d.b.h. or larger, to study how tree characteristics and sawyer factors affect costs. Felling times ranged from 1 minute to more than 2 hours per tree. Felling costs were substantially higher on larger trees, especially on those with certain characteristics that caused felling difficulties: (1) deteriorated, split stems that required felling in more than one piece (2) low forking, which necessitated removal of heavy limbs and additional cuts to reduce stump height and (3) absence of lean or other imbalance. Sawyer experience and sawyer safety were found to be important factors in felling these trees.

The study resulted in a regression of felling time in relation to stem diameter for estimating felling costs. For example, an average felling time of 2.5 minutes per tree can be expected for trees 15 inches in diameter. A regression relating felling

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[4] *Sensitivity analysis within a job can be useful when the variations of the different inputs are in some degree independent and not due to known unusual conditions. Inputs that are related, such as supervision and labor, should be analyzed separately if they vary in daily proportion during typical operations. In this case study, within-job sensitivity analysis was found useful only for the juniper spraying job.*

ime per unit volume to stem diameter was also leveloped for use in estimating juniper harvesting osts. These results are reported separately (Miller nd Johnsen 1970).

Fitting equipment, crew organization, and sawyer ualifications to the job is important to production fficiency. In this case, sawyer crews, saws, and ehicles were those ordinarily employed in pine hinning operations, which may have different reuirements. In situations where sawyers must be ontracted, organization and costs may be consideraly different. More efficient equipment and transortation arrangements should be possible in a ontinuing large-scale operation.

Application of Results

These results and interpretations should be useful s guides to substantial cost reductions through imroved organization, possible changes in prescription, nd further analysis. Possible gains in efficiency hrough further analysis would, of course, need to e balanced against costs of additional study.

The costs presented here can be used for valuating and comparing treatment alternatives. roduction rates and dollar costs should be generally pplicable if such factors as: (1) adjustments in the eneral price level, (2) watershed conditions,[5] and) qualifications concerning crew makeup, supersion, and transportation costs, are adequately condered. Overhead (administration) costs should be stimated and included when evaluating a treatent or practice as an investment, or when comaring alternative treatments.

Transportation costs, as presented in table 3, so need to be included in evaluating alternative erational programs. They can be used in stratiing areas of high and low total treatment costs.

The total cost, in this case $45.02 per acre, can be compared to the additional annual net return in value of products required to break even (table 6). Break-even returns for different planning conditions were calculated with the help of an annuity table. For example, with a planning period of 40 years and an interest rate of 4 percent, an additional annual net return of $2.27 per acre would be required to break even.

Table 6.--Additional annual net return required for the treatment to break even, under alternative planning conditions

Interest rate	Net return required when length of planning period is--		
	20 years	40 years	60 years
	- - Dollars per acre - -		
4 percent	3.31	2.27	1.99
6 percent	3.93	2.99	2.79
8 percent	4.59	3.78	3.64

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[5] *Watershed and tree conditions in this ase study are considered to be typical of orth-central Arizona. The watershed is flat d easily accessible. Much loose surface ck, a characteristic of the soils on the atershed, limited vehicle movement but did t affect other operations. A previous waterhed inventory estimated about 9,000 trees of .5 feet or more in height, of which 96 perent were alligator juniper, and about 800 rees of 9 inches d.b.h. or larger. Maximum .b.h. was 60 inches.*

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 184

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Growth of Ponderosa Pine, White Spruce, and Blue Spruce under Clear and Red Fluorescent Plastic

Richard W. Tinus[1]

Pinus ponderosa, Picea glauca, and Picea pungens tended to be larger and heavier when grown under a covering of red fluorescent plastic rather than under clear polyethylene, although in most cases the differences were not statistically significant. The effects of reduced temperature and altered spectrum were not separated.

KEY WORDS: Pinus ponderosa, Picea glauca, Picea pungens, photosynthesis, greenhouse culture.

Introduction

Conventional greenhouse coverings of glass, f erglass, or flexible plastic transmit visible light c all wavelengths almost equally well. Likewise, c nmonly used shading compounds and screens c sorb light of all wavelengths about equally well. E it has long been known that some wavelengths c much more effective than others for photosynt sis and growth responses (Hillman 1967, (ese 1964).

Polyvinyl chloride film incorporating a red fluorescent dye is available[2] which absorbs green light (525-575 nanometers) and has a strong fluorescence peak at 615 nanometers. Theoretically, red light should be a more efficient energy source for photosynthesis than green light. Hence, when shading is necessary, it may be advantageous to use a spectrally selective material rather than a neutral one. This Note describes a test of the growth of conifer seedlings under a red fluorescent plastic covering in a greenhouse.

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[1] *Plant Physiologist, Rocky Mountain Forest a Range Experiment Station, located at Bottin u, in cooperation with North Dakota State U versity, Bottineau Branch and Institute of F estry; Station's central headquarters maint ned at Fort Collins, in cooperation with C orado State University.*

[2] *"Lifelite" was obtained from Radiant Color Co., Richmond, Calif. Trade and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

Methods

Six compartments 3 feet square and 2 feet high were built on a greenhouse bench inside an unshaded glass greenhouse. The top and south side of each compartment were covered with either 4 mil clear polyethylene or 4 mil red fluorescent polyvinyl chloride. The covering for each of the six compartments was assigned at random. Openings on the lower south side and upper and lower north side were left for air circulation.

Four single-tree seed collections of ponderosa pine (Pinus ponderosa Laws.) were used, two from Valentine, Nebraska, and two from Ruidoso, New Mexico. White spruce (Picea glauca (Moench) Voss) and blue spruce (Picea pungens Engelm.) seeds were obtained in mixed lots from North Dakota State Nursery and Colorado State Nursery, respectively.

Seeds were planted April 4, 1969 in a 3:1 rxture of peat and perlite in No. 10 cans. Two cns of each seed source were prepared for each cnpartment. Seedlings were thinned to four tres per can 4 weeks later. All trees were watered nd fertilized daily with half-strength Hoagland's solutin.

On September 9 and again on November 3, seedlings in one can per seed source per comptment were harvested and measured (table 1).

Mortality was considered in the analysis of viance. Number of trees per seed source per tretment varied from 17 to 24. The analysis yield an adjusted mean which included trees sampled t both sampling times.

The sunlight spectrum in the greenhouse nd under both clear and red fluorescent plastic ws measured with an ISCO spectroradiometer. Hygothermographs were used to monitor temperate

Table 1.--Growth of 5 and 7-month-old seedlings from each seed source, under clear polyethylene and red fluorescent PVC (each figure is an adjusted mean of 17 to 24 trees, dependent upon mortality, from which effect of sampling at two ages has been removed)

Seed source and treatment	Height	Caliper	Weight		Side branches	Needle fascicles	Needl lengt
			Fresh	Dry			
	mm.	mm.	- - gm. - -		no.	no.	mm.
Ponderosa pine:							
Valentine #10							
Clear	155	3.66	16.1	4.83	2.84	61.5	225
Red	176*	3.63	16.4	4.98	3.19	67.9	213
Valentine #8							
Clear	132	3.41	14.4	4.54	1.70	52.4	211
Red	145	3.68	18.0*	5.08	2.71	52.4	220
Ruidoso #4							
Clear	162	4.30	18.4	5.53	2.79	46.5	212
Red	157	4.44	20.5	6.15	3.28	48.6	209
Ruidoso #13							
Clear	143	3.84	16.3	4.68	1.48	39.7	236
Red	153	4.01	19.8*	5.46	1.73	36.5	230
Blue spruce:							
Clear	204	2.62	7.46	1.87	19.4	--	--
Red	218	2.80	7.60	2.11	19.4	--	--
White spruce:							
Clear	122	2.32	3.96	.98	14.4	--	--
Red	150	2.51	5.70*	1.37	16.8*	--	--

Note: "--" indicates not measured.
* Indicates significant difference (5 percent level) between red and clear plastic.

and humidity in one clear plastic compartment and one red plastic compartment.

Results and Discussion

Trees grown under red fluorescent plastic tended to be larger and heavier than under clear plastic, although in most cases differences were not statistically significant (table 1). White spruce under red plastic had 44 percent more fresh weight, 53 percent more dry stem weight, and 17 percent more side branches than under clear plastic. Blue spruce, however, showed no significant differences in any of the measurements.

Response of pine varied considerably with parent tree without respect to geographic location. Trees of one Nebraska source grew 14 percent taller under red plastic than under clear plastic, but no other differences were significant. Trees of the other Nebraska source were 25 percent heavier in fresh weight and had 59 percent more side branches when grown under red plastic, but were not taller. Trees of one New Mexico source grew 22 percent heavier in fresh weight and 24 percent heavier in dry weight under red plastic, whereas trees of the other source showed no significant differences.

Lack of apparent pattern to the differences found may mean that each species and each tree family within species will have to be tested for its response. It is becoming apparent that this is also true of response to irrigation and fertilizer (Jahromi and Goddard 1970, Van Buijtenen and Isbell 1970).

Spectral measurements (fig. 1) confirm the strong absorption of green light and presence of more red light than in direct sunlight. Maximum temperatures in the greenhouse were from 90° to 103° F. during

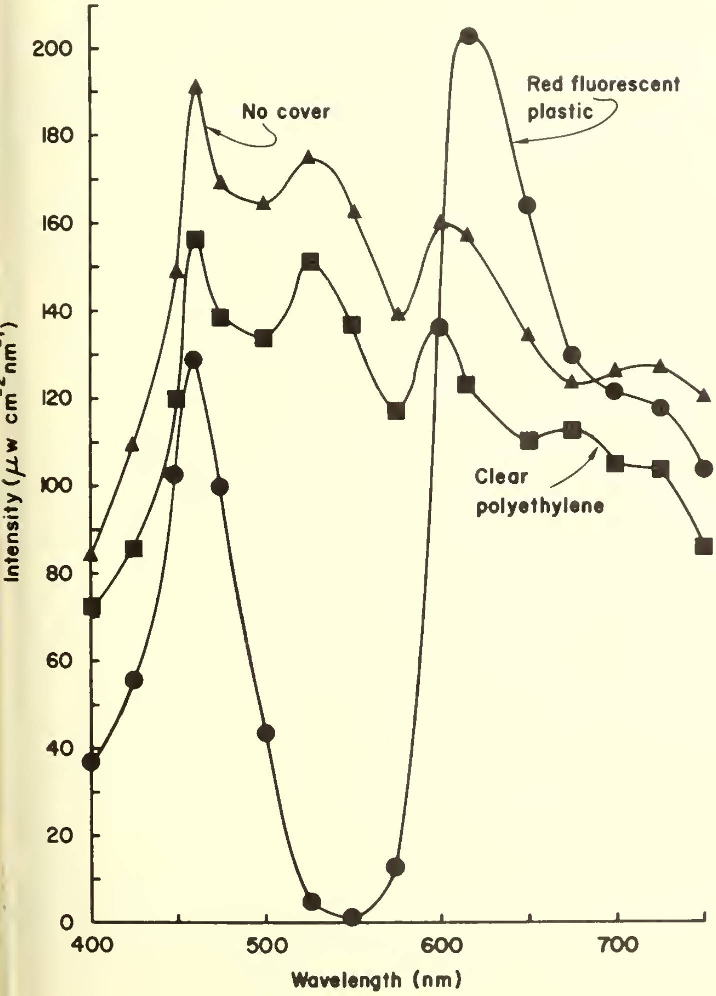

Figure 1.--Comparison of sunlight on a clear day inside a glass greenhouse under red fluorescent polyvinyl chloride, clear polyethylene, and no cover. Measurements were made with an ISCO spectroradiometer at 2 p.m., central daylight time, July 22, 1969.

the summer on clear days. Maximum daytime temperatures under red plastic were 5° to 12° F. lower than under clear plastic, and 0° to 9° F. lower than in the greenhouse under no plastic. Temperatures were the same in all compartments on cloudy days and at night. These observations are similar to those made by other workers.[3] No attempt was made to separate the effect of reduced maximum temperatures from the altered light spectrum under the red plastic.

Conclusion

Enough growth response was obtained in this experiment to warrant further work. A comparison between red fluorescent plastic and a neutral shading that produces the same temperature reduction would be useful. When maximum temperatures must be reduced by shading and the plants being grown respond well to high light intensities, a spectrall selective material might have the advantage ove one which reduces all wavelengths equally.

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[3] *Personal communications from K. L. Goldsberry, Department of Horticulture, Colorado State University, Fort Collins, and D. T. Krizek, Plant Physiologist, Phyto-Engineering Laboratory, USDA Agr. Res. Serv., Beltsville, Md.*

U S D A FOREST SERVICE
RESEARCH NOTE RM- 185

EST SERVICE
. DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fine Herbaceous Fuels in Fire-Danger Rating

Michael A. Fosberg[1]
and
Mark J. Schroeder[2]

Fuel moisture inputs into fire-danger rating or fire behavior models are generally related to fuel classes. To account for as many fuels as possible and still keep the number of inputs to a minimum, we have adopted the procedure of adjusting the fine fuel moisture with respect to the state of the herbaceous vegetation. The adjustment is accomplished by determining the effect of these fuels on rate of fire spread through solutions of simultaneous sets of equations for rate-of-spread, with various proportions of living herbaceous vegetation.

Two extreme cases are presented. In one, the living herbaceous vegetation is completely consumed in the fire. In the other, this vegetation is not burned as the flaming fire front moves through it.

KEY WORDS: Forest fuels, forest fire hazard, forest fire behavior.

Introduction

Fire-danger rating cannot conveniently consider e spectrum of living and dead fuels. Classifition of dead fuels by timelag provides a basis r reducing that part of the spectrum to a managele level. Timelag is defined as the time required r fuels to lose approximately two-thirds of the tial moisture content above equilibrium (actually l/e where e is the base of natural logarithms). is basis for fuel classification led to a 1-hour, 10-hour, and 100-hour fuel system.[3] These fuel classes are for stem materials 1/4 inch and less, 1/4 to 1 inch, and 1 inch to 3 inches in diameter, respectively.

Living fuels in fire-danger rating are geometrically fine, in general, and correspond in size to the 1-hour-timelag dead fuels. However, because they are living, the timelag analysis cannot be applied to them. We consider these living fuels as being part herbaceous and part nonherbaceous material. The nonherbaceous fuels are perennial foliage of brush and reproduction, and woody stems less than 1/4 inch in diameter. The herbaceous

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[3] *Fosberg, Michael A., Mark J. Schroeder, and James W. Lancaster. Dead forest fuels classification by moisture timelag. (Unpublished report on file at Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Fort Collins, Colo.)*

fuels are lesser vegetation such as grasses and ferns.

The above five groups or classes of fuels, three dead and two living, may be used to evaluate the rate-of-spread component in fire-danger rating if their moisture contents are known. In the following development, living herbaceous fuels are combined with the fine dead fuels by means of Rothermel's heterogeneous rate-of-spread model.[4] When herbaceous fuels are dead, they become part of the 1-hour-timelag class of fuels.

Rate-of-Spread Model

Rothermel's spread model is

$$RS = \left[\frac{\Gamma'\zeta(1+\phi_W+\phi_S)h\tilde{\eta}_S}{\rho_B}\right] \frac{\sum_i f_i \tilde{w}_i \tilde{\eta}_m}{\sum_i f_i \sum_j f_{ij} \exp(-138/\sigma_{ij} Q_{ij}}$$

where the rate-of-spread (RS) is directly proportional to the variable terms affecting the propagation intensity $(\sum_i f_i \tilde{w}_i \tilde{\eta}_m)$ and inversely proportional to the heat sink

$$(\sum_i f_i \sum_j [f_{ij} \exp(-138/\sigma_{ij}) Q_{ij}])$$

The bracketed terms on the left are a set of constants (for a given fuel model, wind, and slope) defining the fuel model and the windspeed and slope corrections. Since they are independent of moisture content, they may be grouped into a coefficient and ignored in this analysis. Thus, the rate-of-spread may be expressed as

$$RS \propto \frac{\sum_i f_i \tilde{w}_i \tilde{\eta}_m}{\sum_i f_i \sum_j f_{ij} \exp(-138/\sigma_{ij}) Q_{ij}} \qquad (1)$$

The propagation intensity terms in equation (
are $\tilde{w}_i$, the fuel loading weighted by surface are
and $\tilde{\eta}_m$, the moisture damping coefficient weighte
by surface area, which is given by

$$\eta_m = 1 - 2.59\frac{\tilde{m}}{m_x} + 5.11\frac{\tilde{m}^2}{m_x^2} - 3.52\frac{\tilde{m}^3}{m_x^3} \qquad ($$

where $\tilde{m}$ is the moisture content of the fuels, agai weighted by the surface area of a class, and m_x the extinction moisture content—the point at whi the fuel becomes too wet to support combustio Far dead fuels we have taken this to be fib saturation, or 30 percent, even though it may al be a function of other fuel properties.

We have made several other assumptions (lac ing better information), and developed a line equation for the extinction moisture content f living fuels. We assumed that the heat produce by a burning mass of fuel and transferred to equal mass of unburned fuel is just sufficient raise the temperature of the latter fuel to igniti when the fuels are at a moisture content of percent. If a linear relationship is assumed, the two points define the relation between moistu content and effective heat energy.

The heat of preignition (Q) per unit mass, related to moisture content, is obtained from t rate-of-spread model.

$$Q = 252 + 1116\ m \text{ (Q in B.t.u./lb.)} \quad \text{or}$$

$$Q = 140 + 620\ m \text{ (Q in cal./g.)} \qquad ($$

This relationship is shown as line A in figure Extinction moisture content is defined as the mo ture content above which a fuel will not be ignit by the effective heat. At this point, the effecti heat is just enough to raise the temperature the unburned fuel to ignition and

$$Q_e = Q$$

Consider the ratio of the mass of two fuels one burning and producing heat, and the oth absorbing this heat prior to ignition. If the mass are equal, the ratio is 1. On the basis of the abo assumptions, we can plot two points, one at m = percent and one at m = 25 percent, and then c struct a straight line to m = 0. This is line B the figure.

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[4] *Rothermel, R. C. A mathematical model for fire spread predictions in wildland fuels. (Unpublished report on file at Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Fort Collins, Colo.)*

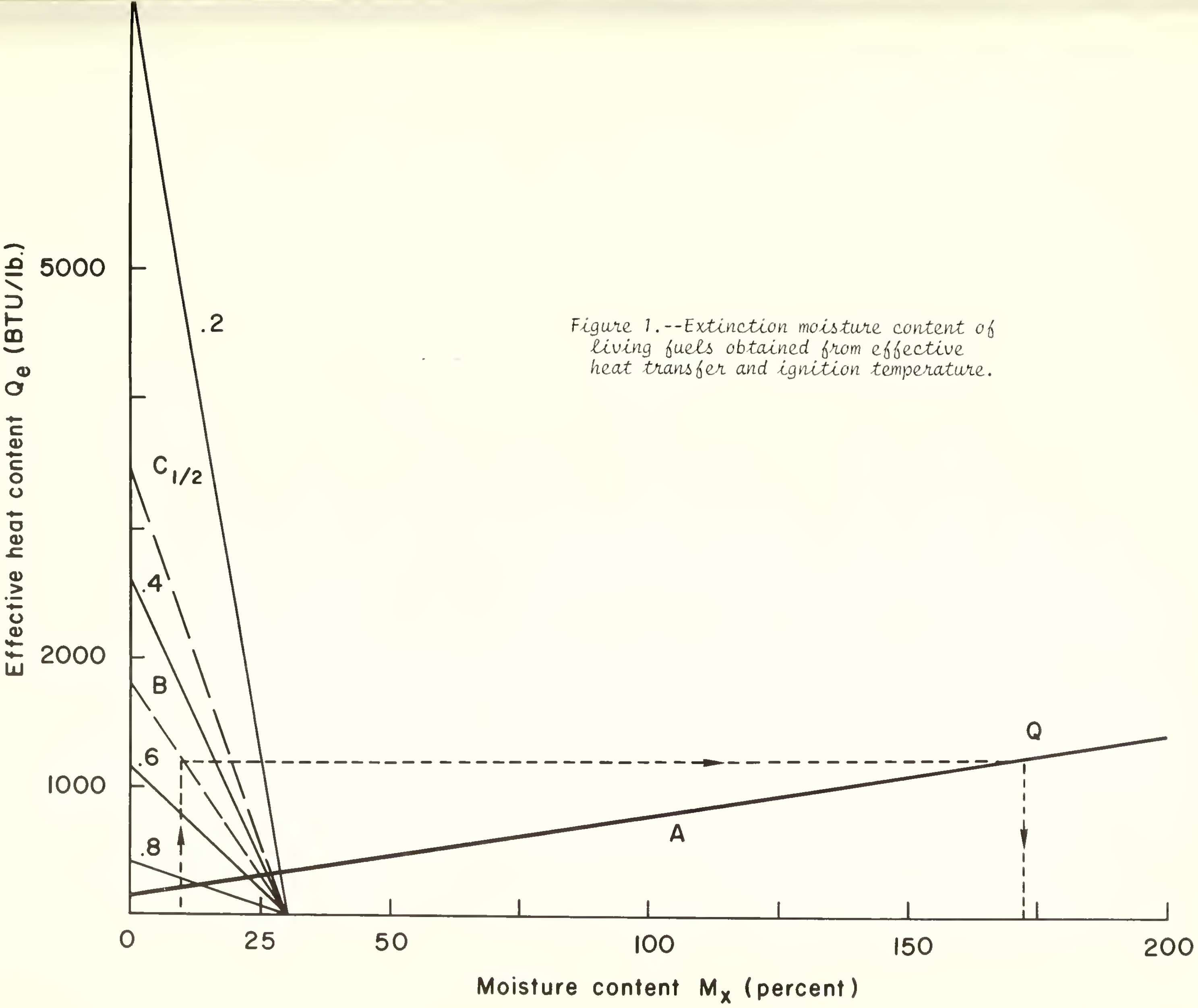

Figure 1.--Extinction moisture content of living fuels obtained from effective heat transfer and ignition temperature.

From lines A and B, we may obtain a graphical solution for the extinction moisture of the fuel to be burned based on the moisture content of the burning fuel. At m = 10 percent, for example (dashed line in the figure), the burning fuel would produce enough effective heat to cause ignition in any equal mass of fuel with a moisture content less than 172.5 percent.

If there were twice as much burning fuel as fuel to be burned, twice as much effective heat would be produced. The ratio would then be 1/2, and the effective heat produced with varying moisture contents is shown by line C in the figure.

Similarly, if there were half as much burning fuel as fuel to be burned, then half as much effective heat would be produced. The ratio would then be 1/0.5.

If we consider the burning fuel as the dead fuel, and the fuel to be burned as the living fuel, we can estimate the extinction moisture content for various proportions of living and dead fuels over the range of dead fuel moisture content from 0 to 30 percent.

In practice, it is easier to consider the fraction of the total fuel which is living, rather than the ratio of living to dead. The ratio then is the mass of living fuel to the total mass of burnable fuel. In the figure, lines are drawn for fractions ranging from 0.2 living to 0.8 living.

The equation for the effective heat is

$$Q = 1800 \left(\frac{1-\alpha}{\alpha}\right) - 6000 \left(\frac{1-\alpha}{\alpha}\right) m \text{ or}$$

$$Q = 1800 \left(\frac{1-\alpha}{\alpha}\right) \left(1- \frac{10}{3} m\right)$$

where α is the fraction of living fuel, and m is its moisture content expressed as a fraction, not percent. Since, at m_x, $Q_e = Q$

$$140 + 620\, m_x = 1800 \left(\frac{1-\alpha}{\alpha}\right) \left(1- \frac{10}{3} m\right)$$

where m_x is the extinction moisture content of the unburned fuel.

Solving for m_x

$$m_x = 2.9 \left(\frac{1-\alpha}{\alpha}\right) \left(1- \frac{10}{3} m\right) - 0.226 \qquad (4)$$

The minimum permissible value for m_x is 0 to prevent negative rates of spread.

The weighting coefficients for surface area a defined as

$$f_{ij} = \frac{A_{ij}}{A_i} \text{ and } f_i = \frac{A_i}{A}$$

where A is the total surface area of all the fu, the subscript i indicates fuel type (living, de) and the subscript j indicates fuel class (1-, 1, 100-hour, or herbaceous, nonherbaceous) within e type. Thus weighted fuel loadings may be -ressed as

$$\tilde{w}_D = f_{1d}w_{1d} + f_{10d}w_{10d} + f_{100d}w_{100d}$$

$$\tilde{w}_L = f_{nL}w_{nL} + f_{hL}w_{hL}$$

where the subscripts i have been replaced wh the explicit living or dead type and the subscri s j have been replaced with the explicit fuel clas s within the type. The weighted moisture conte s may be defined in the same fashion:

$$\tilde{m}_D = f_{1d}m_{1d} + f_{10d}m_{10d} + f_{100d}m_{100d}$$

$$\tilde{m}_L = f_{nL}m_{nL} + f_{hL}m_{hL}$$

The denominator of equation (1) may be develop d in a parallel manner, with σ_{ij} defined as e surface area to volume ratio for the fuel class wit n a type, and Q_{ij} defined as:

$$Q_{ij} = 252 + 1116\, m_{ij}$$

An analysis of the significance of each of e fuel classes in the rate-of-spread model sho s that only the 1-hour-timelag fuels and the her ceous fuels are significant. Thus, the rate-of-spr is

$$RS \propto \frac{f_D w_{1D} \eta_{m1D} + f_L w_{hL} \eta_{mhL}}{f_D \exp(-138/\sigma_{1d})(252+1116m_{1d}) + f_L \exp(-138/\sigma_{hL})(252+1116m_{hL})} \qquad 5)$$

Computing Adjusted Fine Fuel Moisture

If we now assume that the total fuel loading f the 1-hour-timelag class and the herbaceous fuels s a constant, that is, as the herbaceous fuels die, hey become part of the 1-hour-timelag class, we an then state that w_{1d}, the 1-hour fuels are

$$w_{1d} = (1-\alpha)W \tag{6a}$$

nd the herbaceous fuels are given by

$$w_{hL} = \alpha W \tag{6b}$$

here α is the fraction by mass of the living fuels nd W is the total loading of fine fuels. The weighting coefficients by surface area then become

$$\begin{aligned} f_D &= (1-\alpha)W\sigma_{1d} \\ f_L &= \alpha W\sigma_{hL} \end{aligned} \tag{7}$$

ecause the total surface area is given by $\frac{\sigma w}{\rho}$ where is the density and is assumed constant. Definions (2), (6), and (7) may be substituted into (5) give

$$\begin{aligned} \propto &\left[(1-\alpha)^2\sigma\left(1-2.39\,\frac{m_{1d}}{m_{xd}} + 5.11\,(\frac{m_{1d}}{m_{xd}})^2-3.52(\frac{m_{1d}}{m_{xd}})^3\right)\right. \\ &\left. + \alpha^2\sigma_{hL}\;1-2.59\,\frac{m_{hL}}{m_{xL}} + 5.11(\frac{m_{hL}}{m_{xL}})^2-3.52(\frac{m_{hL}}{m_{xL}})^3\right] \\ &\div\left[(1-\alpha)\sigma_{1d}\exp(-138\sigma_{1d})(252+1116m_{1d})\right. \\ &\left. + \alpha\sigma_{hL}\exp(-138/\sigma_{hL})(252+1116m_{hL})\right] \end{aligned} \tag{8}$$

equation (8), m_{xd} is taken to be 30 percent and $_{xL}$ is defined by equation (4).

Our purpose is to define an adjusted moisture ntent for the 1-hour-timelag fuels. Therefore, ropping all the coefficients and terms which are ommon to each expression in the rate-of-spread quation based on the same assumptions used above, is time for an adjusted fine fuel moisture,

$$\propto \frac{1-2.59\,\frac{M}{m_{xd}} + 5.11\left(\frac{M}{m_{xd}}\right)^2-3.52\left(\frac{M}{m_{xd}}\right)^3}{\exp(-138/\sigma_{1d})(252+1116M)} \tag{9}$$

where M is the adjusted fine fuel moisture. Since the terms which were dropped in the spread equation containing the herbaceous fuels were also dropped in the expression for the spread with the adjusted fuel moisture, we will set

$$RA = RS \tag{10}$$

so that the rate-of-spread is the same for both models. Now, by solving equation (10) for M given in equation (9) and employing the terms of equation (8), the adjusted fine fuel moisture becomes

$$M^3 + AM^2 + BM + C = 0 \tag{11}$$

where

$$\begin{aligned} A &= -\frac{5.11m_{xd}}{3.52} \\ B &= \frac{2.59m_{xd}^{\;2}}{3.52} + \frac{1116m_{xd}^{\;3}}{3.52}\;\exp(-138/\sigma_{1d})RS \\ C &= -\frac{m_{xd}^{\;3}}{3.52} + \frac{252m_{xd}^{\;3}}{3.52}\;\exp(-138/\sigma_{1d})RS \end{aligned}$$

Equation (11) yields three roots or solutions for the adjusted fine fuel moisture. Since A, B, and C are real coefficients, the only two possibilities for the roots are three real roots or one real and two imaginary. The only roots of equation (11) that are physically meaningful are the real positive roots.

Example Solutions

We chose two cases of living fuel moisture for fire-danger rating: a green stage of 150 percent moisture content and an intermediate stage of 50 percent moisture content.

The surface area to volume ratios for fuels in the 1-hour-timelag class range between 1000 and 3000 ft.$^{-1}$ [5] However, equation (11) is not very sensitive to the exact value of σ so we have chosen σ_{1d} = 1500 ft.$^{-1}$ The surface area to volume ratio for the herbaceous fuels was assumed to be 750 ft.$^{-1}$. This value was chosen because we felt the surface area would be nearly the same, but the herbaceous fuels would have about twice the

[5] *Brown, James K. Ratios of surface area to volume for common fine fuels. Forest Sci. 16: 101-105, illus. 1970.*

volume because of the swollen nature of living fuels.

We solved equation (11) for a range of dead fuel moisture contents between 1.5 and 30 percent, and percentage of living material between 5 and 80 percent. These solutions (table 1) then define the range of conditions normally encountered in fire-danger rating.

This solution represents one extreme in adjusted fine fuel moisture. It implies that the living herbaceous fuels are consumed in the same fashion as the dead fuels. The other extreme, that of no living fuels involved in the flaming front, may be expressed as

$$RS \propto \frac{(1-\alpha)\left(1-2.59\frac{m_{ld}}{m_{xd}}+5.11\left(\frac{m_{ld}}{m_{xd}}\right)^2-3.52\left(\frac{m_{ld}}{m_{xd}}\right)^3\right)}{(252+1116m_{ld})\exp(-138/\sigma_{ld})} \qquad (12)$$

This form of the model implies that the fire moves through the living fuels sufficiently fast that they are not involved. The physical effect here is to reduce the fuel loading as opposed to the firs case where a heat sink was involved. The adjuste fine fuel moisture is obtained in the same fashio as before, by solving equation (11), but equatio (12) is used for RS rather than equation (8). Th adjustments here (table 2) are much less pronounce than those in table 1, primarily because the hea sink has been removed.

Summary

The effect of the presence of varying proportion of living herbaceous vegetation on rate-of-sprea can be determined by solving a rate-of-spread equa tion which includes the moisture content and quar tity of both living and dead fuels as parameter This effect can be incorporated into fire-dange rating by determining an adjusted fine fuel moistur content through solution of simultaneous rate-of spread equations. One equation in the set consider the living and dead fine fuels as separate classe of fuels. The other considers them as one fue

Table 1.--Adjusted fine fuel moisture contents in percent, when all fine living fuel is consumed in the flaming front

Percent living	One-hour-timelag fuel moisture, percent														
	1.5	2.0	2.5	3.0-3.5	4.0-4.5	5.0-5.5	6.0-6.5	7.0-8.0	9.0-10.0	11.0-12.0	13.0-16.0	17.0-20.0	21.0-25.0	26.0-30.0	30.0+
Green stage															
5	3.3	3.8	4.4	4.9	6.1	7.3	8.5	10.5	13.3	15.9	18.6	21.2	24.2	28.2	30.0
10	5.3	5.9	6.5	7.2	8.6	10.2	11.9	14.8	17.9	19.7	21.3	22.9	25.1	28.5	30.0
15	7.6	8.4	9.2	10.1	12.2	14.4	16.6	19.0	20.9	22.0	23.0	24.2	25.8	28.7	30.0
20	10.8	11.9	13.1	14.4	16.9	18.8	20.2	21.7	22.8	23.6	24.3	25.1	26.4	28.9	30.0
25	15.3	16.7	17.8	18.8	20.4	21.6	22.4	23.4	24.2	24.7	25.2	25.8	27.0	29.1	20.0
30	19.5	20.3	21.0	21.6	22.6	23.3	23.9	24.5	25.1	25.5	25.9	26.4	27.7	29.2	30.0
40	23.6	24.0	24.3	24.5	25.0	25.3	25.6	26.0	26.3	26.6	26.9	28.0	28.5	29.4	30.0
50	25.5	25.7	25.8	26.0	26.2	26.5	26.7	27.1	27.6	28.3	28.7	28.8	29.0	29.6	30.0
60	27.9	28.1	28.4	28.7	28.8	28.9	29.0	29.1	29.1	29.2	29.2	29.3	29.4	29.8	20.0
Transition stage															
5	2.5	3.0	3.6	4.1	5.1	6.2	7.4	9.1	11.6	14.0	17.1	20.3	23.8	28.2	30.0
10	3.6	4.1	4.7	5.2	6.4	7.6	8.9	11.0	14.1	16.7	19.2	21.5	24.4	28.3	30.0
15	4.7	5.3	5.9	6.5	7.8	9.2	10.8	13.4	16.6	18.8	20.7	22.5	24.9	28.4	30.0
20	5.9	6.5	7.2	7.9	9.4	11.1	13.0	15.9	18.7	20.3	21.8	23.3	25.3	28.6	30.0
25	7.2	8.0	8.7	9.5	11.3	13.3	15.4	18.0	20.2	21.4	22.6	23.9	25.7	28.8	30.0
30	8.7	9.5	10.4	11.4	13.5	15.7	17.6	19.6	21.3	22.3	23.3	24.4	26.0	29.0	30.0
40	12.5	13.6	14.7	15.8	17.8	19.2	20.4	21.6	22.7	23.4	24.2	25.1	26.3	29.2	30.0
50	16.9	17.8	18.6	19.2	20.3	21.2	21.9	22.7	23.5	24.0	24.6	25.3	28.4	29.4	30.0
60	19.8	20.3	20.7	21.0	21.7	22.2	22.6	23.1	23.6	24.0	24.7	28.2	29.0	29.6	30.0

Table 2.--Adjusted fine fuel moisture contents in percent, when no fine living fuel is consumed in the flaming front

Percent living	One-hour-timelag fuel moisture, percent													
	1.5	2.0	2.5	3.0-3.5	4.0-4.5	5.0-5.5	6.0-6.5	7.0-8.0	9.0-10.0	11.0-12.0	13.0-16.0	17.0-20.0	21.0-25.0	26.0-30.0	30.0+
5	1.9	2.4	3.0	3.5	4.5	5.6	6.6	8.3	10.5	12.8	16.0	19.6	23.5	28.1	30.0
10	2.4	2.9	3.5	4.0	5.1	6.2	7.4	9.1	11.7	14.3	17.5	20.6	24.0	28.2	30.0
15	2.9	3.5	4.0	4.6	5.7	6.9	8.2	10.2	13.2	16.0	18.8	21.4	24.4	28.3	30.0
20	3.5	4.0	4.6	5.2	6.5	7.8	9.2	11.5	14.9	17.6	20.0	22.2	24.9	28.4	30.0
25	4.1	4.7	5.3	6.0	7.3	8.8	10.4	13.2	16.8	19.1	21.1	23.0	25.3	28.5	30.0
30	4.8	5.4	6.1	6.8	8.3	10.0	11.9	15.2	18.5	20.4	22.1	23.6	25.7	28.6	30.0
40	6.6	7.4	8.2	9.1	11.2	13.7	16.3	19.1	21.3	22.6	23.7	24.8	26.4	28.8	30.0
50	9.3	10.4	11.7	13.1	16.2	18.7	20.4	22.1	23.5	24.3	25.1	25.9	27.1	29.0	30.0
60	14.5	16.3	17.8	19.1	21.0	22.3	23.3	24.3	25.2	25.7	26.3	26.9	27.7	29.2	30.0
70	21.1	22.0	22.7	23.2	24.2	24.9	25.4	26.1	26.6	27.0	27.3	27.7	28.4	29.4	30.0
70	25.1	25.4	25.8	26.0	26.5	26.9	27.2	27.5	27.9	28.1	28.3	28.5	28.9	29.6	30.0

lass but with an adjusted moisture content. Equatng the rates of spread from the two equations perits one to solve for the adjusted moisture content.

Solutions were derived for two extreme cases. he first considered the living fuel as being comletely consumed in the fire. The second condered the living fuels as not burning as the fire assed through the fuel bed. The most applicable alue probably lies between these two extremes. is not possible at present, however, to deterine intermediate values because the heat transfer rocess in the flaming front is not defined for heterogeneous fuels. The second solution, that of leaving the living fuel unburned, is probably closer to reality than the first solution. In preliminary trials of the National Fire-Danger Rating System, the second solution is being used.

Laboratory experiments are needed to determine more precise input values for the rate-of-spread equation. For example, the extinction moisture contents used for both dead and living fuels are crude estimates. Laboratory experiments are also needed to verify empirically the effect of living fuels on rate of spread.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-186

REST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Browsing Preference by Jackrabbits in a Ponderosa Pine Provenance Plantation

Ralph A. Read[1]

Black-tailed jackrabbits, in a young ponderosa pine plantation of 79 provenances in central Nebraska, browsed the western sources more heavily than sources from east of the Continental Divide.

KEY WORDS: *Lepus californicus*, *Pinus ponderosa*, *tree breeding*, *genetics*.

Although ponderosa pine is not listed among
e food items of jackrabbits (Hansen and Flinders
69), plantations of it in Washington have been
maged by rabbits (Squillace and Silen 1962).
ough not abundant in the ponderosa pine region
Arizona and New Mexico, jackrabbits browse the
edles and buds in winter when snow is deep
earson 1950). Snowshoe hares (*Lepus americanus*)
mmonly damage plantations of jack pine, Douglas-
Port-Orford-cedar, and western hemlock (Krefting
53, Staebler et al. 1954). This Note documents
mage by black-tailed jackrabbits (*Lepus californicus*
lanotis Mearns) to small ponderosa pines (*Pinus*
nderosa Laws.) in a Nebraska plantation of West-
de provenances. Further, the data support, in
rt, the conclusions of other studies that progeny
certain provenances (origins or geographic sources)
ponderosa pine are preferred over others by
bbits, deer, and other animals.

Plantation Description

Thirty-three acres of level, open land were planted to 2+1 ponderosa pine stock near Hastings, Nebraska, in May 1968. A well-established stand of alfalfa was plowed in March of that year to accommodate the pine plantations. The area supported a fairly large population of jackrabbits—20 to 40 were often counted in a quarter section.

Trees were planted 8 feet apart in rows 12 feet apart, and were arranged in 25-tree (5x5) plots. Seventy-nine plots of different geographic origins were randomly located within each replication. Three of the replications were contiguous on an area of 650 by 1,320 feet. A fourth replication was a quarter mile from the others. Most of the origins were from east of the Continental Divide in North Dakota, Montana, Wyoming, South Dakota, Nebraska, Colorado, and New Mexico. Four origins were from the Bitterroot Valley in western Montana, and one each from Idaho, Oregon, Washington, and Arizona.

Over 100 jackrabbits were shot during the spring planting on this area. Although there was an abundance of green forbs, grasses, and resprouting alfalfa, jackrabbits began browsing the ponderosa

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pines during the summer soon after planting. Beginning in October and throughout the winter of 1968, browsing increased, despite the shooting of an additional 90 jackrabbits. The tree crowns were clipped off at 4 to 8 inches aboveground, but normally the tops remained uneaten. Stem caliper at point of cutoff ranged from 1/4 to 1/2 inch. The plantations were fenced with 3-foot-high, 1-inch-mesh chicken wire in February 1969, and have suffered no further damage.

Variation in Damage Pattern

Although the jackrabbits had equal access to all plots, browsing was heaviest on plots containing seedlings of origins from western Montana, Washin ton, Oregon, Idaho, and Arizona (table 1). Th pattern was found in all blocks, although the tot number of browsed trees was significantly larg in two of the four blocks. In an extreme exampl all 25 trees in one plot of a western Montana orig (#817) were cut off, while only a few in adjace plots had been touched. This pattern of browsi use (fig. 1) was fairly consistent throughout tl plantation. Trees of many different origins we browsed very lightly or not at all, even thou trees on adjacent plots were heavily browsed. N apparent relationship of browsing to topograp or plant cover can explain the damage, since the characteristics are essentially uniform througho the area.

Table 1.--Percentage of 3-year-old ponderosa pine trees of different origins browsed by jackrabbits at Hastings, Nebraska, winter 1968

Region of origin	Number of origins	Percent of trees browsed[1]	Origins alike[2]
West of Continental Divide			
N. central Washington	1	57	a
Central Oregon	1	55	a
Lower Bitterroot Valley & Missoula, Montana	2	58 to 60	a
Upper Bitterroot Valley, Montana	2	25 to 32	ab
Helena, Montana[3]	1	33	b
SW. Idaho	1	25	b
Flagstaff, Arizona	1	24	b
Mean		41	
East of Continental Divide			
N. central Montana	7	6 to 13	c
S. central Montana	5	8 to 18	c
Missouri River Plateau[4]	8	4 to 13	c
Big Horn Mountains & adjacent	4	2 to 11	c
Black Hills & adjacent	8	3 to 21	c
Pine Ridge & Niobrara River[5]	11	2 to 19	c
N. Platte River & Lodgepole Creek[6]	10	3 to 17	c
Front Range, N. Colorado	8	5 to 20	c
Front Range, S. Colorado & N. New Mexico	6	5 to 21	c
S. central New Mexico	3	7 to 9	c
Mean		10	

[1] Basis: 100 trees of each origin.

[2] Homogeneous subsets in multiple range analysis.

[3] Although east of the Divide, the ponderosa pine here is contiguous with the distribution west.

[4] E. Montana, SW. North Dakota, and NW. South Dakota.

[5] E. central Wyoming, NW. Nebraska, and S. central South Dakota.

[6] SE. Wyoming and W. Nebraska.

768 1	857 0	838 0	762 2	851 2	761 0
840 1	824 0	832 2	812 0	▨ 865 11	701 0
864 3	852 0	839 0	859 2	767 5	701 0
858 6	847 0	724 1	836 4	820 6	854 0
846 0	765 1	838 0	▨ 817 25	855 4	▨ 866 12
▨ 863 10	822 0	829 0	766 3	721 1	828 0
759 0	845 0	812 3	814 3	857 3	727 2
▨ 865 14	764 0	862 1	856 0	853 0	837 0
844 2	▨ 816 20	827 0	758 1	824 2	811 1
813 0	722 0	703 1	831 0	834 0	815 2

Figure 1.--Plot layout of a portion of two blocks, showing origin identification numbers and numbers of trees (of 25) that were browsed by jackrabbits. Heavily browsed origins (shaded) were:

816 -- Helena, Montana
817 -- Missoula, Montana
863 -- N. New Mexico
865 -- central Oregon
866 -- N. central Washington

The differences in browsing preference by jackrabbits appear to be related to genetic variation n the tree species. Differences in browsing preference by rabbits (species not stated) among 10 ponderosa pine seed sources in a Washington plantation were reported by Squillace and Silen (1962). In hat study, sources of central California, central Arizona, and western Oregon were most heavily browsed, while sources of southern Oregon, Bitteroot Valley of Montana, northern New Mexico, and Black Hills of South Dakota were browsed lightly or not at all. Why browsing damage on Bitterroot Montana origins is so different between the Washingon and Nebraska plantations is not easily explained. Browsing preferences by a different species of jackabbit or less pressure by fewer jackrabbits in Washngton are possible factors.

Studies of genetic variation in the range-wide distribution of ponderosa pine have indicated there are six or more ecotypes (Weidman 1939, Wells 1964, Wright et al. 1969). In the northern range, ponderosa pine in western Montana, Idaho, and eastern Washington and Oregon is considered to be a different ecotype from the pine in central Montana and eastward. Jackrabbit browsing in the Nebraska plantation was heaviest on origins within the ecotype west of the Continental Divide (table 1). In the southern range, the central Arizona and southern New Mexico ecotype is separated from other ecotypes in the central Rocky Mountains. While browsing was light on the south central New Mexico origins, it was quite heavy on the Arizona origin.

Analysis of chemical constituents (turpentine composition) of ponderosa pine from a limited number of sources showed differences in the amounts of certain fractions (Mirov 1961). The fraction called longifolene was not found in any of the four California and Idaho sources analyzed, for example, although varying amounts were found in other sources from the eastern part of the species range, including Utah and Arizona. Data are not available for western Montana, Washington, and Oregon sources. This example is not intended to show any relationship between longifolene content and jackrabbit browsing; it is given only to illustrate the genetic variation within one species of pine. More intensive sampling of chemical composition of ponderosa pine over its entire range might help to clarify relationships between pine ecotypes and browsing preferences of rabbits and other animals.

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U S D A FOREST SERVIC
RESEARCH NOTE RM- 187

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

An Infrared De-icing Unit for Cup Anemometers

Arthur Judson[1]

Electric infrared lamps yielding 0.5 watt radiant energy per square centimeter of cup surface prevented icing on an exposed mountain anemometer in Colorado. The unit performed well during all rime conditions for two consecutive winters. Parts for the inexpensive unit are commercially available.

KEY WORDS: Meteorological instruments, anemometers, ice (rime).

Accurate measurement of winter windspeed on m untains is essential in evaluating hazard from s w avalanches. Ice is the primary cause of instrum nt error at such locations because it accumulates o the sensors, slows the response time, and eventu lly stops or seriously damages the instrument. W d stations on the Forest Service's weather, snow, a l avalanche reporting network (Judson 1971) are lc ted on exposed ridge crests and mountain summ s where avalanches start. Most of these sites are a ve the cloud base during storms, where icing is eaviest.

Rime and clear ice are the important ice accumul ons affecting mountain-based anemometers. Rime (f . 1) forms from impact freezing of supercooled cl d droplets; it is white, opaque, and sometimes fe thery. Clear ice forms when supercooled cloud d plets impact, splash, then freeze on objects. R e is the more frequent of the two icing forms

Figure 1.--Soft rime accumulation on the unheated, three-cup anemometer at the Colorado site.

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[1] *Meteorologist, Rocky Mountain Forest and nge Experiment Station, with central headarters maintained at Fort Collins, in coopation with Colorado State University.*

in the mountains. It may be soft, with a density low of 200 kilograms per cubic meter (kg m^{-3}) or hard, with a density ranging from 600 - 900 kg m^{-3} (Boyd and Williams 1968).

Accumulation rates are roughly proportional to the liquid water concentration in the cloud, cloud-drop diameter, temperature, windspeed, and the collection efficiency of the object accumulating ice. The collection efficiency of an object depends on its physical dimensions. In general, small objects are more efficient ice collectors than are large ones.

Because various finishes and specially prepared coatings designed to prevent rime adhesion on cup anemometers have not worked satisfactorily, sensors are often placed in sheltered sites below the rime line. The resulting record is influenced by local terrain, and is not representative of wind conditions at many avalanche sites. We have assembled a de-icing unit for those exposed sites where line power is available. It was successfully tested at a high mountain station in Colorado. No attempt was made to de-ice the vane other than coating it with black paint. This Note reports on the unit and the icing conditions under which it has performed during the winter 1968-69.

Unit Design

The heating unit at the Colorado site (fig.) consists of three General Electric Par 56 medi flood, 120-volt, 300-watt lamps mounted in Ste fixture S401.[2] The lamps are protected by Steber clear cover lens S402. The S401 fixt is mounted in junction box S345 at 90° interv. A metal brace firmly holds each lamp at an o mum angle to direct radiant heat on the a mometer cups. The lamp faces are 46 centimet (cm) below the cups. Line power for this unit available at the site. The lamps are turned on a off from the base station about a mile away use of a remote switching circuit (fig. 3).

Figure 2.--Electric infrared de-icer and cup anemometer on the 12,493-foot summit of Colorado Mines Peak. The unit performed well during winters 1968-69 and 1969-70.

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[2] *Trade names and company names are us for the benefit of the reader, and do not i ply endorsement or preferential treatment the U. S. Department of Agriculture.*

Cost

Total cost of the unit is about $175. Parts are commercially available:

Item	Distributor	Cost Unit	Cost Total
GE lamps Par 5o MFL 120-V 300-W	Consolidated Electric Distributors	$6.25	$18.75
Steber fixtures:			
Lamp holder S401	Pyle National Co., Steber Division	8.06	24.18
Cover lens S402		1.88	5.64
Junction box S345		1.56	1.56
Welding of junction box on tower, all-weather cable, switching circuit, fusing, and tie into power source	Local sources		125.00
			$175.13

Heating Output

Ninety percent of the incandescent lamp output is infrared. The spectral energy chart for the Par 56 lamps gives the following distribution:

Spectrum	Wavelength (Nanometers)	Output (Percent)
Infrared	780+	90
Visible	380-780	8
Ultraviolet	300-380	2

Each lamp emits 3840 lumens. Since 1 lumen is approximately equal to 0.05 watt of radiated energy,[3] each lamp yields 192 watts at the lamp

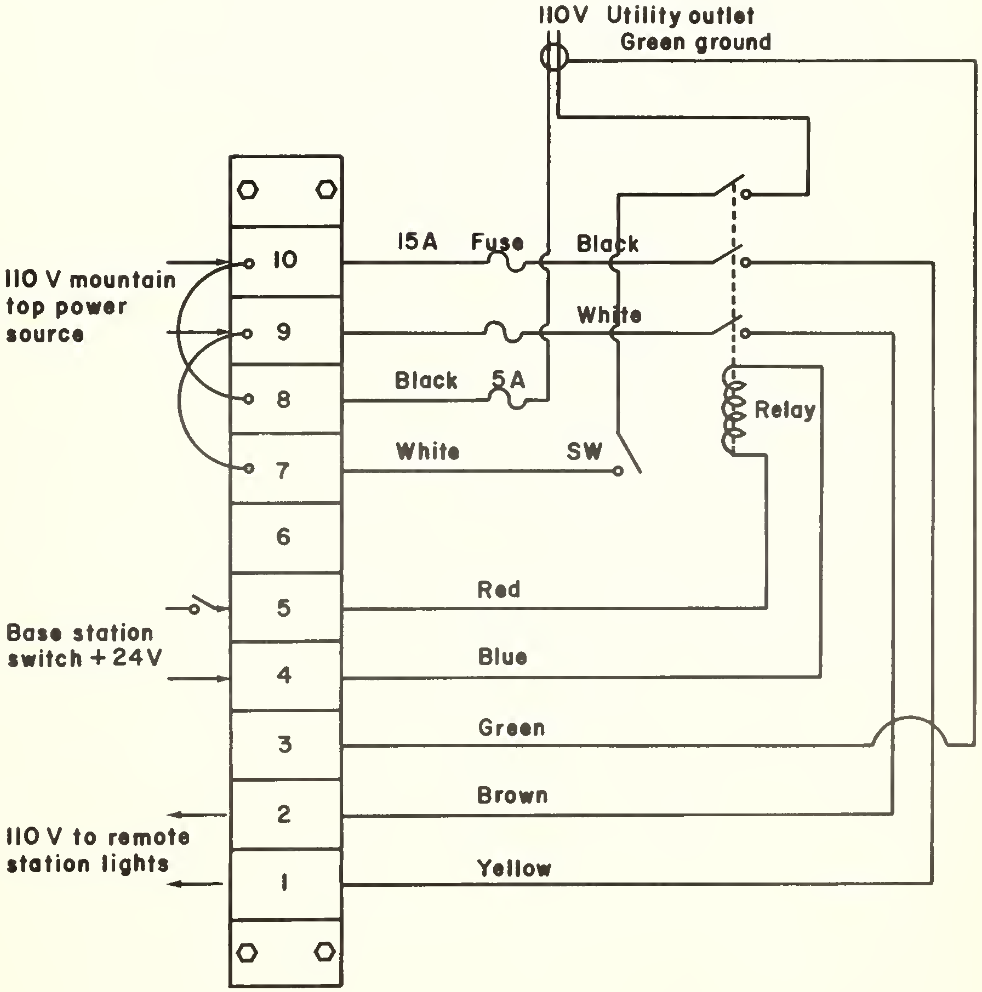

Figure 3.-- Switching circuit used to turn the de-icing equipment on and off at the remote site. One-way line length was about 4,400 feet. The 24 V power supply energizes the relay at the remote site, which allows the 110 V mountain-top source to turn on the incandescent lamps.

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[3] Personal correspondence with Carl J. Allen, Color Specialist, General Electric Company.

face. We used a simple water calorimeter to determine the total radiant flux available to the cups with the S402 cover lens on. A lamp was placed 46 cm from the calorimeter. The total radiant flux was calculated at 125 W, or 0.5 W per cm^{-2} of cup surface. This compares with the heating requirement given by Kuroiwa (1965) to prevent icing on wires in Japan, but is considerably less than the 2 - 4 W cm^{-2} determined by Schaefer (1947) in his experiments on Mount Washington, New Hampshire. Icing conditions on Mount Washington are more severe than those on the Colorado site, however. Also, more heat is required to prevent icing on the small-diameter cylindrical rod used by Schaefer, since its collection efficiency is greater than that of the cups.

Unit Performance and Rime Conditions Encountered

We tested the infrared lamps on the 12,493-foot summit of Colorado Mines Peak near Berthoud Pass. Two anemometers were used in the tests during the 1968-69 winter. One was unheated, and both were coated with a high-gloss black paint to aid radiation absorption. The heated anemometer remained rime-free during the entire period, even when rime accumulations exceeded 30 cm on the supporting tower. Rime affected the unheated wind sensor for 800 hours from November through April. Neither the heating unit nor the heated anemometer were damaged; the unheated sensor was seriously damaged twice and had to be replaced. We found that 2.5 cm of soft rime on the cups produced a 50 percent negative error with a windspeed of 13 meters per second ($m\ sec^{-1}$). Accumulations frequently exceeded 2.5 cm. Thus a substantial portion of mountain wind records during storms are worthless unless de-icing equipment is used.

Temperatures during riming ranged from -18° to -3°C., while windspeed varied from 4 to 56 m sec^{-1}. Observed soft rime events outnumbered hard rime by an order of magnitude. On the average, observed rime accumulations were 2.5 times thicker on the supporting tower than on the cups. Accumulations were greatest on small-diameter stationary objects. Accretion of wet snow was not observed because the warm temperatures and low windspeed favorable for this condition are rare on this high summit. There was no detectable difference in the windspeed record produced by the heated and unheated anemometers during periods with no rime.

The unit performed well again during winter 1969-70 at the Colorado site and also at an exposed summit in the Wyoming Tetons.

Recommendations

The heating unit described here has been recommended as the minimum standard equipment or weather, snow, and avalanche reporting network stations. At the mountain stations on the West Coast where liquid water concentrations are high and riming is severe, we are testing Par 64 500 W lamps and adding a fourth light to the junction box. Current information on the adequacy of the heating units at various stations may be obtained by contacting the author.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-188

ST SERVICE
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MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Crown Competition Factor (CCF) for Engelmann Spruce in the Central Rocky Mountains

Robert R. Alexander[1]

The relationship between crown width and stem diameter at breast height for open-grown trees is presented for Engelmann spruce in the central Rocky Mountains. Maximum Crown Area (MCA) in square feet can be estimated from diameter in inches. The relationship of MCA to diameter is the basis for computing Crown Competition Factor (CCF), a measure of stand density.

Crown Competition Factor (CCF) is a measure of tand density developed by Krajicek et al (1961). C compares space occupied by a tree with that re esented by the vertical projection of the average cr vn area of an open-grown tree of the same diam er. The percentage of an acre occupied by the ve ical projection of the crown—obtained by dividing th area in square feet by 435.6—is the Maximum C wn Area (MCA). Because space occupied by a si le tree is not easily determined, the comparison is nade on a stand basis. CCF is the sum of the M A values of all trees in the stand divided by th area in acres. Although it pertains to crowns ai is expressed in percent, CCF is not a measure o crown closure, but a measure of the growing sp ce available to the average tree in the stand in relation to the maximum area it could use if it were open-grown (Krajicek et al. 1961, Vezina 1962).

CCF has proved useful in comparing different measures of stand density, and establishing relationships between growth and density. Species tested include: upland oaks (Quercus alba L., Q. rubra L., and Q. velutina Lam.), shagbark hickory (Carya ovata (Mill.) K. Kock), and Norway spruce (Picea abies (L.) Karst.) (Krajicek et al. 1961); white spruce (P. glauca (Moench) Voss.), balsam fir (Abies balsamea (L.) Mill.), and jack pine (Pinus banksiana Lamb.) (Vezina 1962, 1963); and lodgepole pine (P. contorta Dougl.) (Alexander et al. 1967).

Methods

To establish the relationship between crown spread and stem diameter at breast height for open-grown trees—a necessary prerequisite to developing a CCF equation—116 free-growing Engelmann spruces (Picea engelmanni Parry) were measured

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[1] *Principal Silviculturist, Rocky Mountain Fc est and Range Experiment Station, with cent l headquarters maintained at Fort Collins, i cooperation with Colorado State University.*

in Colorado. Only those trees that met the following specifications (Krajicek et al. 1961) were included in the sample:

1. Crown free of competition on all sides.
2. Live branches extending to the ground or nearly so.
3. Lowest branches longest or at least as long as those above, indicating no release from past competition.
4. No evidence of forking, or storm, disease, or insect damage.

Sample trees were generally found in meadows, open parks, and old burns. No trees were selected below 9,000 feet elevation because observations indicated that free-growing trees in city parks, cemeteries, and along roads below the natural elevational range of spruce had wider crown spreads.

Crown width of each sample tree was the average of two measurements of maximum green width, made at right angles to each other with a ta e. Diameters were measured at breast height wit a diameter tape.

Relation of Crown Width to Diameter

The linear regression of average crown wi h (CW) in feet on diameter breast height (D) in incl s is:

$$CW = 4.344 + 1.029D$$
$$r = 0.99 \qquad 1)$$
$$s\bar{y} = 1.321 \text{ feet}$$

The relationship of crown width to tree diam er (fig. 1) applies specifically to open-grown Eng lmann spruces in Colorado and southern Wyomi g, and only to trees with diameters at breast hei t not larger than 30 inches. A few larger trees w e sampled, but were not included in the analy is because a scatter diagram indicated that the r e

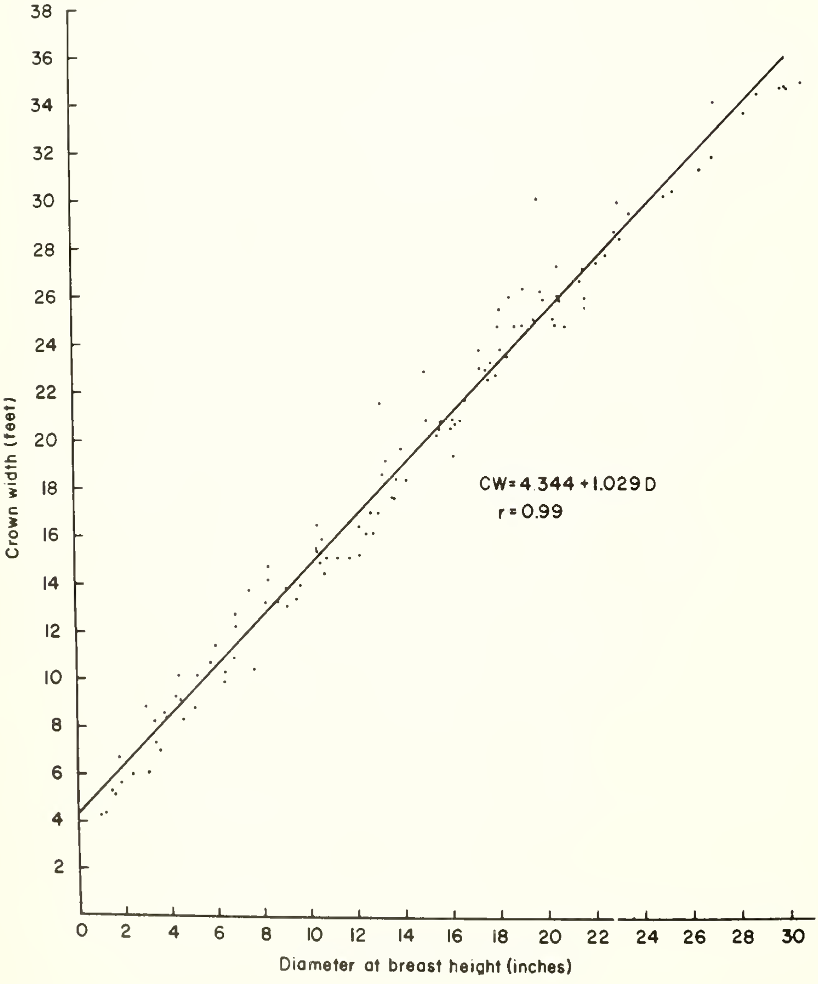

Figure 1.--Relationship of crown width to stem diameter at breast height for open-grown Engelmann spruce.

of change in CW with D was slower for trees larger than 30 inches d.b.h.

The CW-D relationship for open-grown spruces is significantly different from that established for lodgepole pines (CW = 3.27 + 1.423D), a common associate in the central Rocky Mountains (Alexander et al. 1967). Open-grown spruces have much narrower crowns than lodgepole pines at any given diameter up to 30 inches d.b.h.

CCF for Engelmann Spruce

The maximum percentage of an acre that can be occupied by the crown of an Engelmann spruce of specified bole diameter is:

$$MCA = \frac{\pi\ (CW)^2 \times 100}{4 \times 43{,}560} = 0.0018\ (CW)^2$$

From equation 1

$$CW^2 = 18.8729 + 8.9406D + 1.0588D^2$$

Therefore,

$$MCA = 0.0340 + 0.0161D + 0.0019D^2 \qquad (2)$$

CCF for a spruce stand can now be estimated from a stand table by either (a) summing the MCA values for each diameter class and dividing by the area in acres, or (b) accumulating the MCA values of the trees in the stand in the following form:

$$CCF = \frac{1}{A}\left[0.0340 \sum_{i=1}^{k} N_i + 0.0161 \sum_{i=1}^{k} D_i N_i + 0.0019 \sum_{i=1}^{k} D_i^2 N_i\right] \qquad (3)$$

D_i = ith d.b.h. class
N_i = number of trees in ith d.b.h. class
A = area in acres
k = number of d.b.h. classes in stand

An example of the computation of CCF for an Engelmann spruce stand by both (a) and (b) is given in table 1.

Table 1.--Determination of the CCF in an Engelmann spruce stand. Plot size 0.4 acre

D (d.b.h.)	N_i	DN	D^2N	MCA per tree	Total MCA
4	27	108	432	0.129	3.483
5	25	125	625	.162	4.050
6	18	108	648	.199	3.582
7	14	98	686	.240	3.360
8	11	88	704	.285	3.135
9	2	18	162	.334	0.688
10	3	30	300	.386	1.158
11	4	44	484	.442	1.786
12	6	72	864	.502	3.012
13	7	91	1,183	.566	3.962
14	3	42	588	.634	1.902
15	5	75	1,125	.705	3.525
16	4	64	1,024	.780	3.120
17	2	34	578	.860	1.720
18	2	36	648	.942	1.884
19	3	57	1,083	1.029	3.087
Total	136	1,090	11,134		43.416

$$CCF = \frac{\text{Total MCA}}{\text{Area in acres}}$$

$$CCF = \frac{43.416}{0.4}$$

$$CCF = 108.54$$

$$CCF = \frac{1}{A}\ [0.0340\ (136) + 0.0161\ (1090) + 0.0019\ (11134)]$$

$$CCF = \frac{43.328}{0.4}$$

$$CCF = 108.32$$

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U S D A FOREST SERVIC
RESEARCH NOTE RM- 189

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Calibrating the Snow Particle Counter for Particle Size and Speed

R. A. Schmidt and E. W. Holub[1]

Laboratory calibration of a photoelectric snow particle counter shows the device gives useful estimates of particle speed and size without large temperature corrections, although some field adjustments are necessary for optimum performance.

KEY WORDS: Snow (particle size), instrumentation, snow samplers.

The work reported here is part of a program to ieasure snow transport by wind in alpine areas, ith the ultimate goal of predicting and controlling iow deposition. The instruments used in these ieasurements are a modification of the original esign by Hollung, Rogers, and Businger.[2] The iodified instrument was described by Schmidt and ommerfeld.[3]

Briefly, the device (fig. 1) produces an electrical gnal when an individual particle passes through a ollimated light beam directed at two slits (fig. 2). vo photo transistors, one behind each slit, are onnected in a bridge circuit (fig. 3). The bridge utput is amplified by the differential amplifier produce a signal of the form shown in figure 4. ich signals may be recorded on analog magnetic tape and counted electronically to give the total number of snow particles which passed through the active volume of the counter.

Since the output of the photo transistor depends on the amount of light blocked by the particle, the amplitude of the output signal should provide an estimate of particle size. Further, the time between the beginning of the positive and negative portions of the signal, together with the known slit separation, should allow us to estimate the component of particle velocity perpendicular to the slits. These two calibrations and the system temperature response are the subject of this Note.

The Calibrator

Adjusting the particle counters initially requires some method of obtaining a standard signal. The device described here works well for both laboratory and field situations. A bare solid wire of sufficient diameter (0.5 mm.) to completely shadow one slit was heated and forced into the edge of a plastic disc (about 8 cm. diameter). The wire extended along a radius from the disc for about 3 cm. The disc was fastened to the shaft of a small d.c. motor (of the model car variety) and the motor was

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[1] Associate Hydrologist and Forestry Reearch Technician, respectively, Rocky Mt. orest and Range Exp. Sta., with central headuarters maintained at Fort Collins in cooper-tion with Colorado State Univ.

[2] Hollung, O., W. E. Rogers, and J. A. usinger. Joint Tech. Rep. Dep. Elec. Eng., ep. Atmos. Sci., Univ. Wash., Seattle. 54p. 966.

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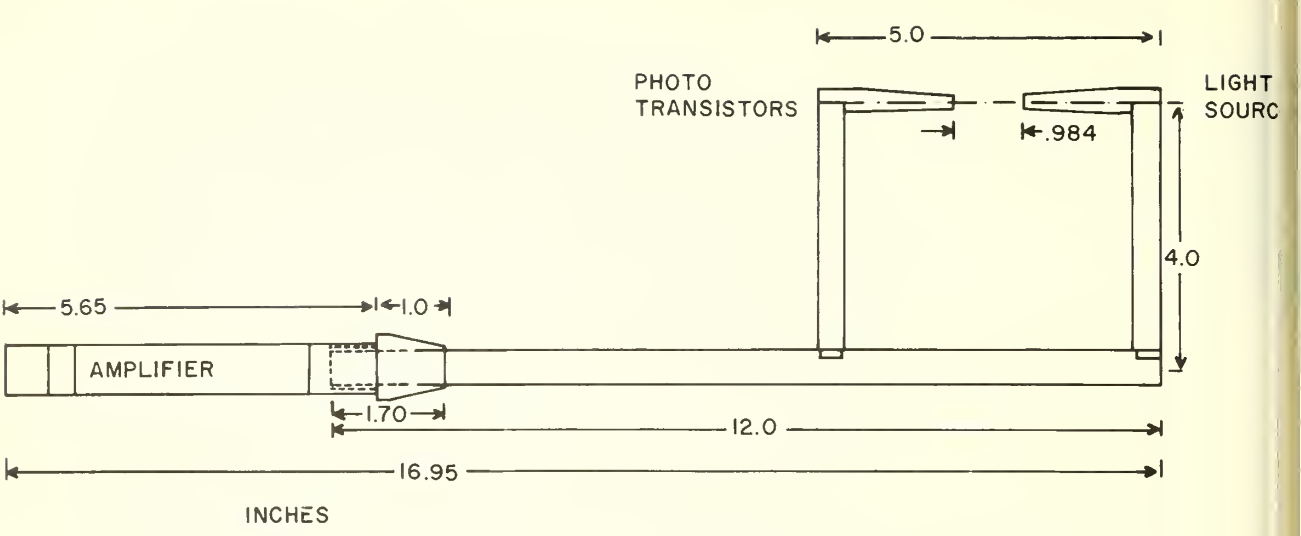

Figure 1.--Dimensions of the photoelectric snow particle counter.

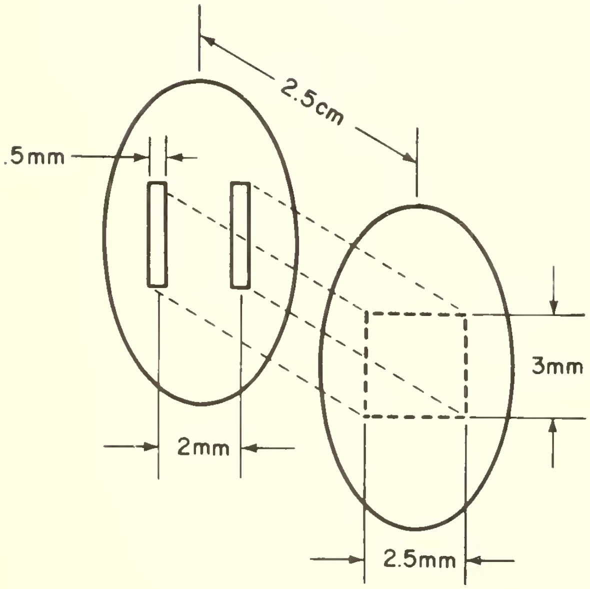

Figure 2.--Dimensions of the active volume of the counter.

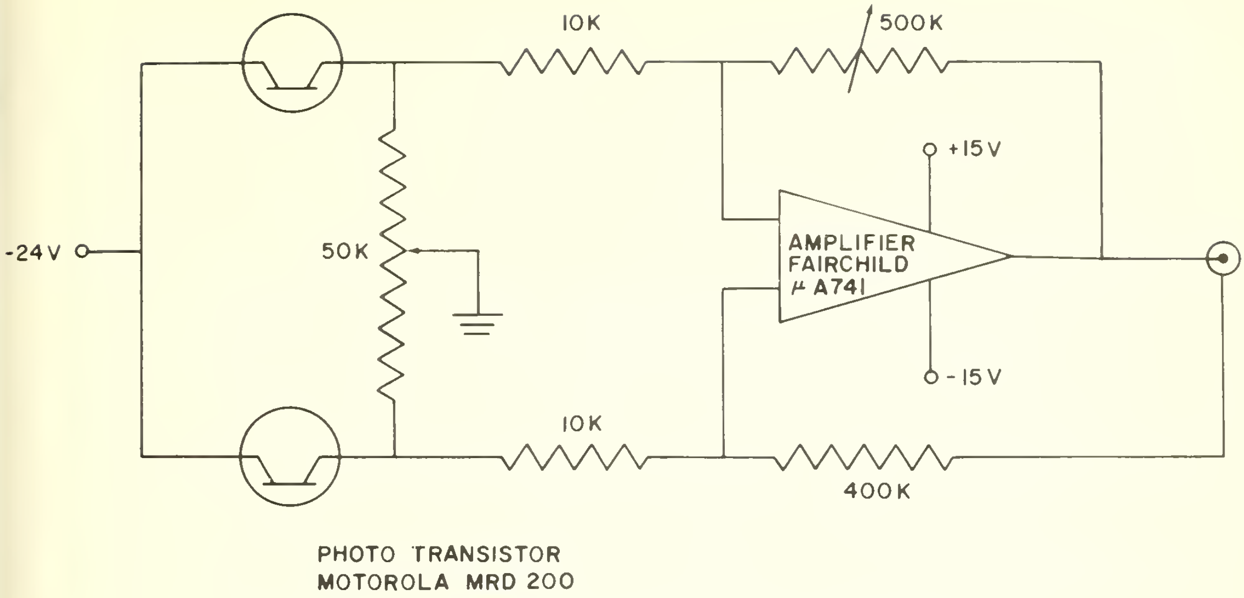

Figure 3.--Circuit diagram of the sensors and amplifier.

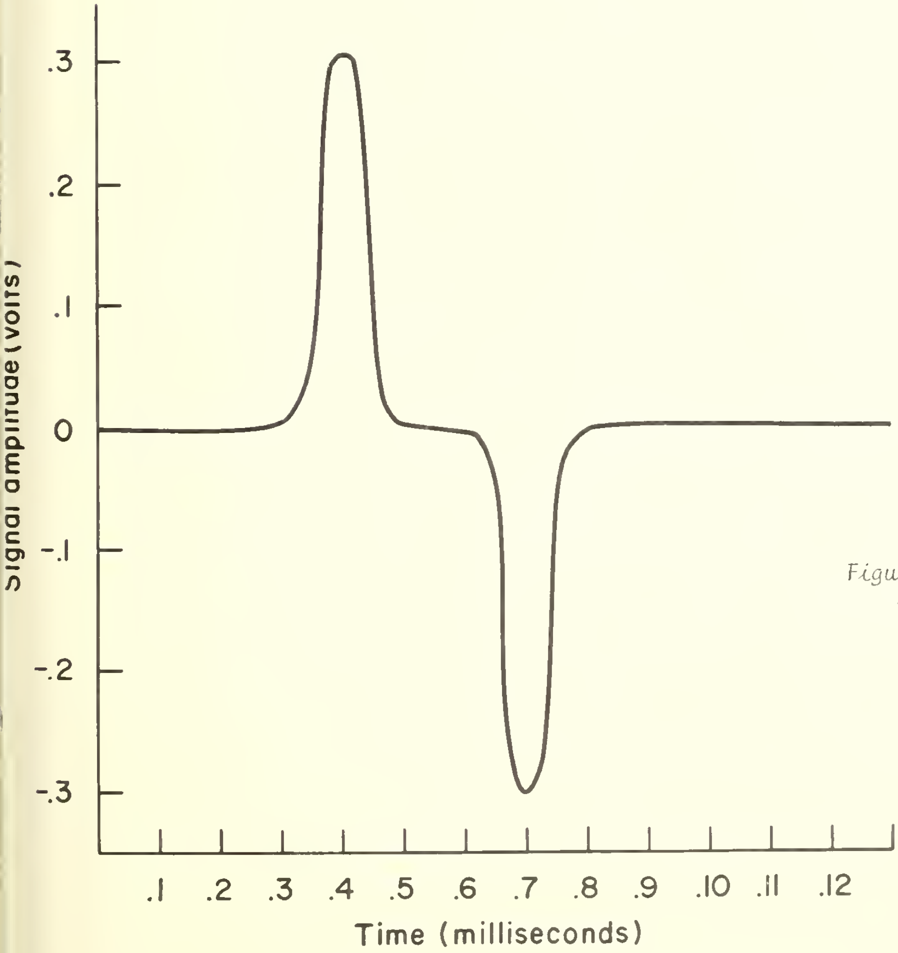

Figure 4.--Typical snow particle signal from the counter.

mounted in the head of a right-angle flashlight (fig. 5). The motor was connected through the flashlight switch to two 1.5 V "D" cells in the handle.

For field calibration, the calibrator is handhel so the wire moves through the light beam in th direction of particle travel. The calibrator

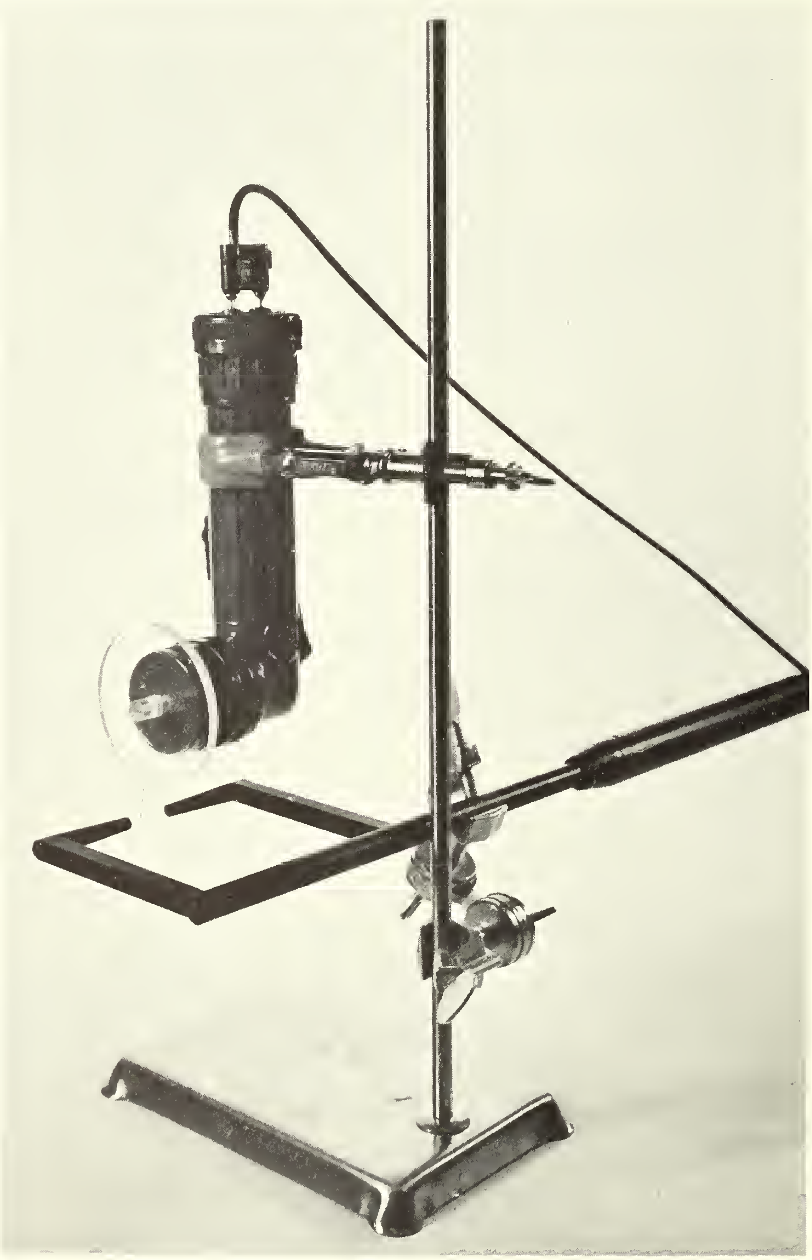

Figure 5.--The particle counter calibrator unit.

clamped to a ring stand for laboratory calibration, and the batteries are removed. A variable-voltage power supply connected to the motor through 'banana'' jacks in the bottom of the handle allows he motor speed to be adjusted.

Particle Counter Adjustments

If the voltage to the light source is held constant, there are only two adjustments to the particle caunter output. First the amplifier gain is adjusted by the 500 K variable-feedback resistor to give the desired signal amplitude for the calibrator wire ±3.0 volts was the usual setting). The second adjustment is made with the 50K potentiometer which forms the passive side of the bridge. This setting balances the positive and negative portions of the signal, and compensates for differences in photo transistor response. The two adjustments are made alternately until the desired output signal s obtained with the calibrator. (With no obstruction n the light path, the counter will have a d.c. output different from zero. This output is removed by a blacking capacitor before recording particle signals.)

Particle Size Calibration

The objective here was to relate the signal amplitude from the particle counter to the size of snow particles. To work out techniques, sieved sand particles were initially used in the laboratory. Then the apparatus was moved to a cold room and the experiment was repeated with snow particles sieved into size fractions from natural samples which had been stored in a freezer.

The particle-counter output was terminated across a 2K resistor and fed through a 15 mfd capacitor to a storage-type oscilloscope. After adjusting the particle counter for ±3.0 volts with the calibrator, a number of particles (usually 40 to 50) of one sieved size fraction were dropped past the counter. The storage scope displayed the output, and the average positive signal amplitude was estimated from the display.

The counter gave similar outputs for both materials (fig. 6). The nearly linear relation was not anticipated. Since the projected or shadow area of the particle is proportional to the second power of particle diameter, a parabolic relation was expected. Apparently, the linear output results

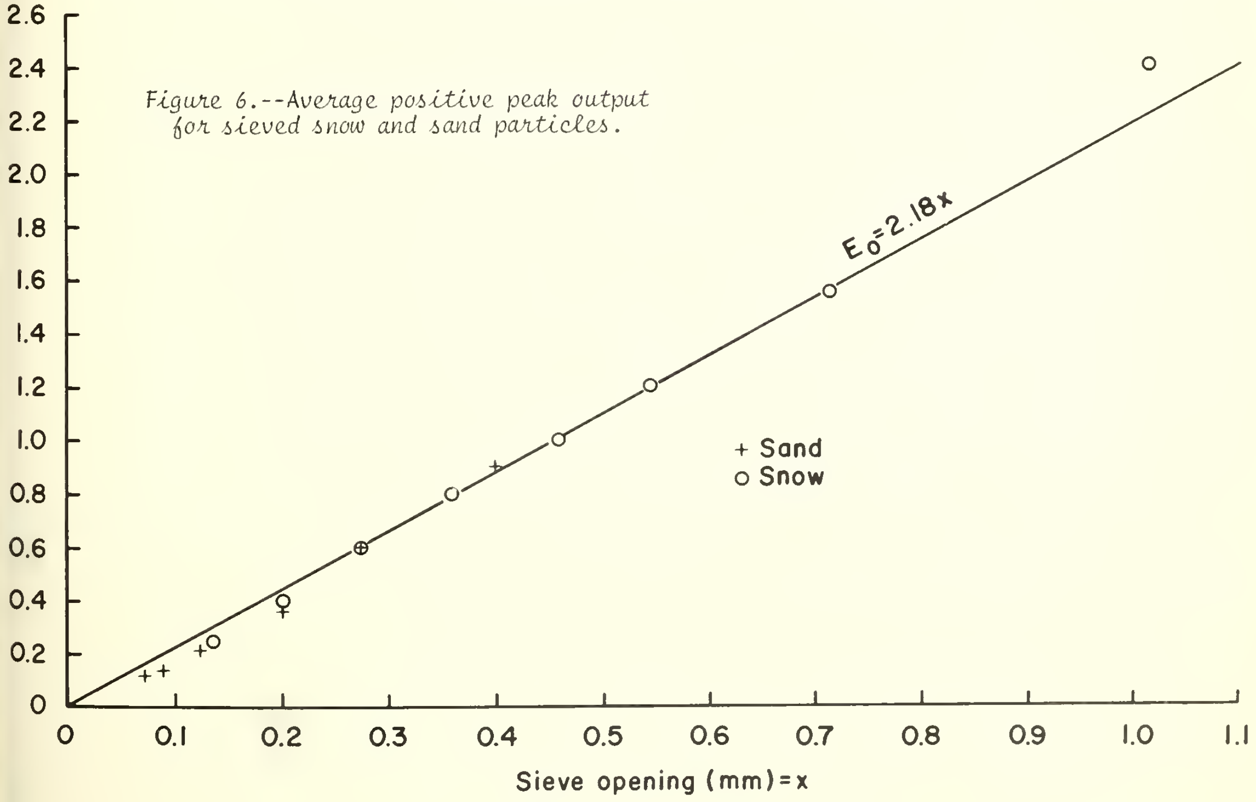
Figure 6.--Average positive peak output for sieved snow and sand particles.

from a combination of factors, including the photo transistor response and amplifier characteristics. In short, the linear relation is considered fortuitous.

This method of calibration ignores a few important considerations, one of these being the variation in particle shape. There were, of course, variations in the amplitudes for a given size fraction, some of which were due to size variation within the sample and some that must be due to particle shape. The calibration in figure 6 must be viewed only as the average output for a sieved size fraction, and is appropriate for analyzing a large number of particle signals.

Particle Speed Calibration

The effectiveness of the particle counter for measuring particle speeds depends on the fall time of the photo transistors and the rise time of the amplifier. Both were selected to allow speeds of more than 10 m. sec.$^{-1}$ to be measured, but calibration was necessary to see how well this goal was achieved. The output of the particle counter was terminated as before and connected to a time-interval counter with variable trigger levels. Again the output was set to ±3.0 volts for the calibrato wire. The time-interval counter was set to trigge on at +0.1 volt on the rising limb of the positiv signal and off at -0.1 volt on the falling limb o the negative signal.

Two methods were used for the calibration, bot in a laboratory at room temperatures. The firs was to vary the speed of the calibrator wire b adjusting the power supplied to the motor. Th angular speed of the motor was determined b electronically counting the frequency of signals fron the particle counter. This count was converted t the tangential speed of the wire by measurin the radius to the top of the slits.

The second method used particles of sand, plasti and lead blown through the particle counter by a air jet. The particles were photographed with variable-frequency strobe light, and the particl speed was determined from the distance betwee exposed particle positions and the strobe ligh frequency.

Both methods show (fig. 7) that the particl counter and time-interval counter tend to ove estimate particle speed in a linear fashion. Thi overestimate is most likely due to response charac teristics of the various components.

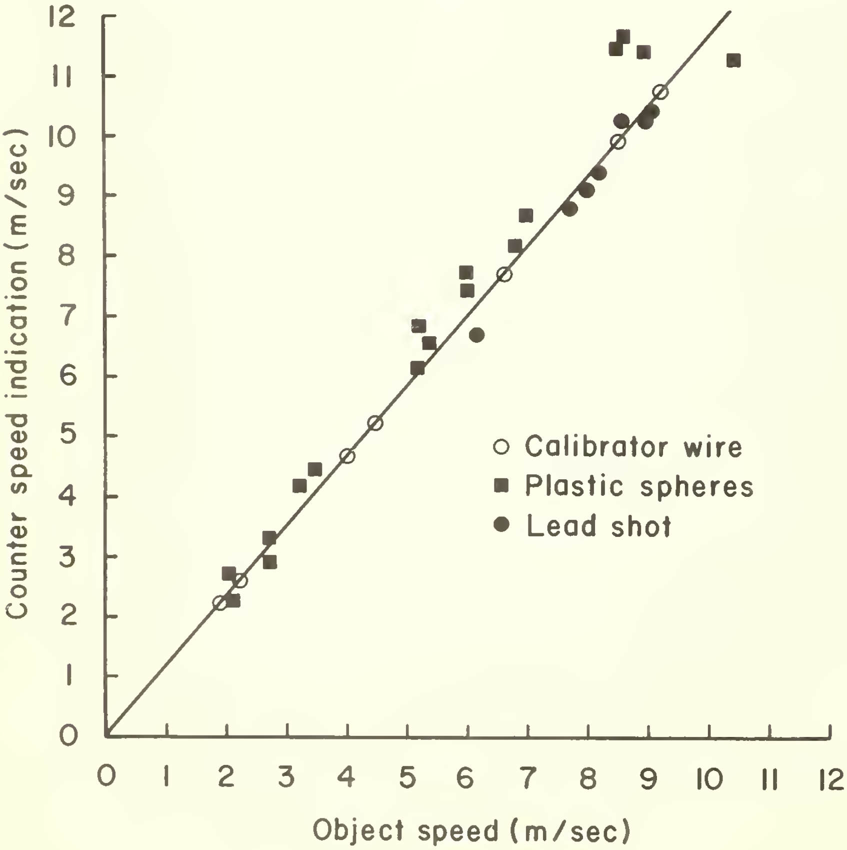

Figure 7.--Speed indicated b particle counter as a function of actual speed.

Speed-Size Interaction

Apparently there is no significant interaction etween the signal amplitude and the speed at hich the particle moves through the counter in ıe range from half a meter per second to more ıan 10 meters per second. Individual particles several sizes were blown through the counter at fferent speeds, and the output for each size, as ewed on a storage oscilloscope, did not change gnificantly with speed. The slight variations were tributed to the fact that the particles were not erfectly spherical.

Temperature Response

For the particle counter to be useful, it must be relatively free from output variations due to temperature change. During the design, this requirement was considered in specifying circuit components especially for temperatures below freezing. The temperature response of each particle counter was tested in a cold room over the range from 0° to -15° C. Each counter was adjusted to give ±3.0 volts output from the calibrator wire at -15°C. Temperatures were increased over the range, allowing several hours for equilibrium at each setting. The results (fig. 8) indicate that a temperature change of a few degrees has only a small effect on the output, but it also demonstrates the importance of calibrating the counters in the field before a series of runs at about the same temperature.

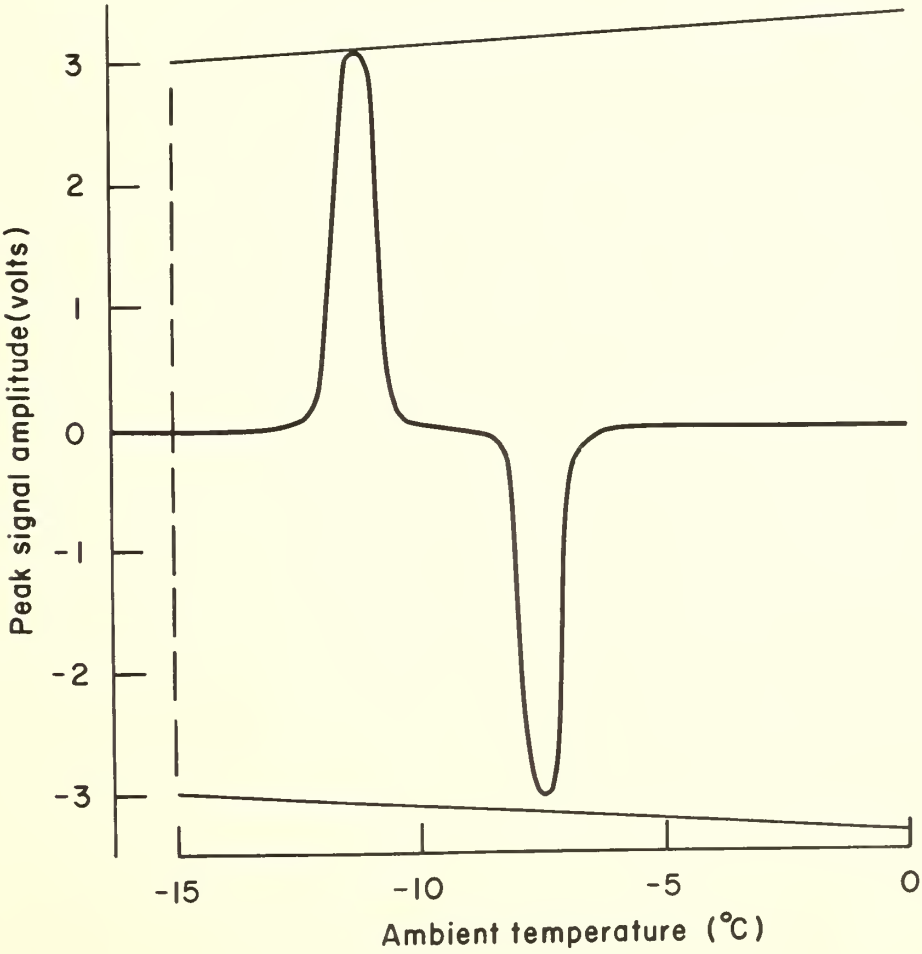

Figure 8.--Particle counter temperature response.

Conclusions

1. The signal amplitudes of the photoelectric snow particle counter yield an estimate of snow particle size. For sieved snow this relation is $E_0 = 2.18\ X$, where E_0 is the positive peak output in volts and X is the sieve opening.
2. The component of particle speed perpendicular to the slits may be estimated from the relation $S = 1730/t$, where S is the speed in meters per second and t is the time in microseconds, c determined from the particle-counter signal wit a time-interval counter.
3. Signal amplitude and thus particle size estimate are independent of particle speed for the rang 0.5 to 10 m. sec^{-1}.
4. Adjustments are necessary in the field befor runs, but changes in output are small for normc temperature changes during runs of 30 minute or less.

U S D A FOREST SERVICE
RESEARCH NOTE RM-190

EST SERVICE
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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Evaporation from Bare Soil as Affected by Texture and Temperature

Ralph E. Campbell[1]

Evaporation of water under several drying conditions was studied in six soils from the semiarid upper Rio Puerco drainage of New Mexico. Evaporation from initially saturated soils exposed to the atmosphere was 0.33 inch per day at 90°F. and 0.22 inch per day at 60°F. Sandy soils lost half of their moisture in 5 and 7 days at 90° and 60°F., respectively, compared to 8 and 15 days for clay soils under similar conditions. After rapid initial moisture loss, the dried surface of sandy soils acted as a barrier to further moisture loss.

KEY WORDS: Soil moisture, soil temperature

Inadequate soil moisture presents one of the most itical management problems in watershed areas the Southwest. In the upper Rio Puerco water- ed, the season of maximum precipitation is also e season of maximum temperature and evapora- e stress. Attempts to reseed sparsely vegetated nds to grasses may succeed only if soil moisture adequate. One of the important initial steps evaluating sites for range reseeding or establish- g vegetation for erosion control is to understand e patterns of evaporation from various soils follow- g storm events.

Reported here is a study of comparative drying tes among soils of differing texture. The soils ere held at two constant temperatures and dried om saturation in early summer and early fall. aporation rates were also compared on these soils when they were supplied with small increments of water, simulating light rain showers.

Limitations of environmental control during these studies reduced some of the comparisons to an observational basis, so conclusions from some aspects of the study are somewhat subjective.

Many studies have related the drying of bare soils to the environmental factors which influence drying. Moisture movement in the soil and, subsequently, evaporation from the soil, are functions of soil moisture content, soil moisture potential gradients, temperature gradients, diffusivity, and conductivity, as well as evaporative stress factors above the soil surface. Evaporation from soil under constant evaporative stress can be approximately described by a nonlinear partial differential equation with the aid of computers (Hanks et al. 1969), but with the natural variability in soils and the variety of evaporation stress conditions encountered in the field, an explicit mathematical expression of evaporation is impractical if not presently impossible. Thus when describing the evaporation from a particular set of soils or making comparisons among them, it is still expedient to determine evaporative losses experimentally.

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[1] *Soil Scientist, located at Albuquerque cooperation with the University of New xico; station's central headquarters main- ined at Fort Collins in cooperation with lorado State University. Research reported re was conducted in cooperation with the reau of Land Management, U. S. Dep. of the terior.*

Table 1.--Textural classification, particle size distribution, and moisture content at saturation, -1/3 and -15 bar matric potential of six soils from the Cabezon area, upper Rio Puerco, New Mexico

Two-letter map symbol	Soil series, texture	Particle size distribution			Moisture content		
		Sand	Silt	Clay	Saturation	-1/3 bar potential	-15 bar potential
		- - -	- - -	- - -	-Percent-	- - -	- - -
Br	Berent loamy fine sand	77	11	12	29.9	8.7	4.0
Pf	Penistaja fine sandy loam	45	43	12	32.0	8.2	3.7
Au	Alluvial land (sandy loam)	47	36	17	45.2	22.2	9.5
Ps	Persayo silt	17	82	1	47.0	25.2	14.9
Cg	Christianburg (clay loam)	29	34	37	45.0	24.8	10.6
Ng	Navajo clay	2	37	62	61.0	40.4	21.6

The soils used in the study (table 1) were: Berent loamy fine sand, Penistaja fine sandy loam, alluvial land (sandy loam), Persayo silt, Christianburg clay loam, and Navajo clay. All these soils have been correlated, and are described by Folks and Stone (1968). Moisture contents of the six soils at -1/3 and -15 bars matric potential are also shown (table 1).

The study was comprised of three pot experiments. Each is presented here serially, and all are then briefly discussed jointly. Surface soils were air-dried and passed through a 1/4-inch-mesh wire cloth screen to eliminate large clods before being placed in pots.

Santa Fe Experiment

Procedure.—The first of the three experiments was conducted in a small green fiberglass-walled shelter at the Forest Service Laboratory at Santa Fe, New Mexico. The six soils were replicated four times in each of two constant-temperature baths. Temperatures were maintained at 60°F. and 90°F. ±2°. The shelter walls around the tanks extended about 4 feet above the top of the pots. The canvas roof was removed except when rain was expected. Air-dried soils were placed in pots 6 inches in diameter and 9 inches deep, lined with a plastic bag. All pots of a given soil were the same weight, filled to 8.5 inches and uniformly packed. Enough water was added to each pot to saturate the soil at the beginning of each of two dryin periods of about 45 days. Evaporation began o May 13, 1968. The second drying, with the 60°F temperature bath only, began on August 24. Calcu lations were based on readings made daily for th first 10 days, and at 5-day intervals thereafte

Results.—Evaporation is expressed as percen of applied water used, and is plotted against tim (figs. 1-3).

The initial drying rate was rapid and quite un form, as described by Gardner (1961), but differe significantly among soils. Evaporation was mor rapid from the sandy soils than from the clay soi The differences among soils were greater at 90 than at 60° F. The initial drying phase, whe evaporation was primarily a function of atmospheri stress, was followed by a transitional phase durin which the drying rate decreased, apparently as function of soil-moisture distribution. This was fo lowed by a third phase during which evaporatio continued at a nearly constant but much lower rat and appeared to be a function of heat flux. Th change from the first through the second and t the third phase was relatively abrupt in sandy soi in comparison with the clay. The transition fro the first to the second phase occurred at a slightl lower moisture content at 90° than at 60°F. considerably greater percentage of moisture wa lost from the sandy soils than from the clay befor they passed from the first phase into the secon and more time was required. This was particularl

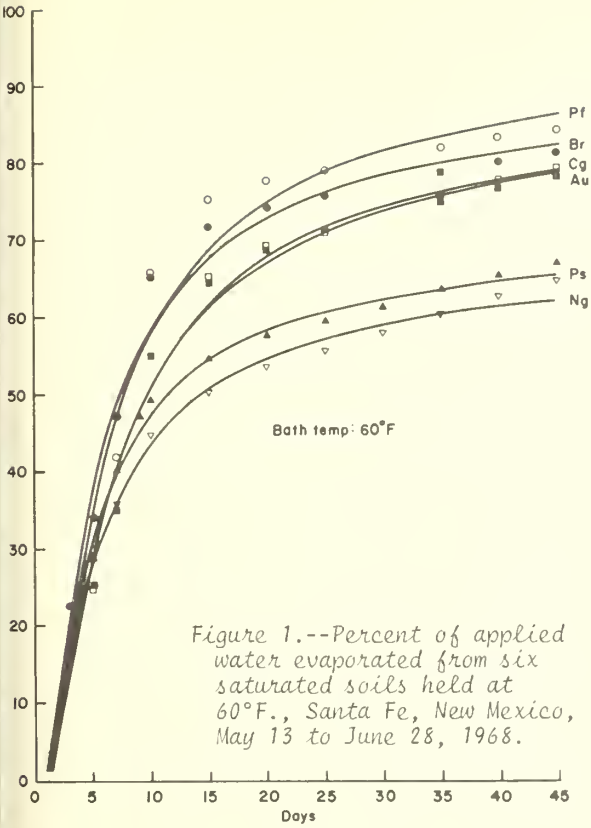

Figure 1.--Percent of applied water evaporated from six saturated soils held at 60°F., Santa Fe, New Mexico, May 13 to June 28, 1968.

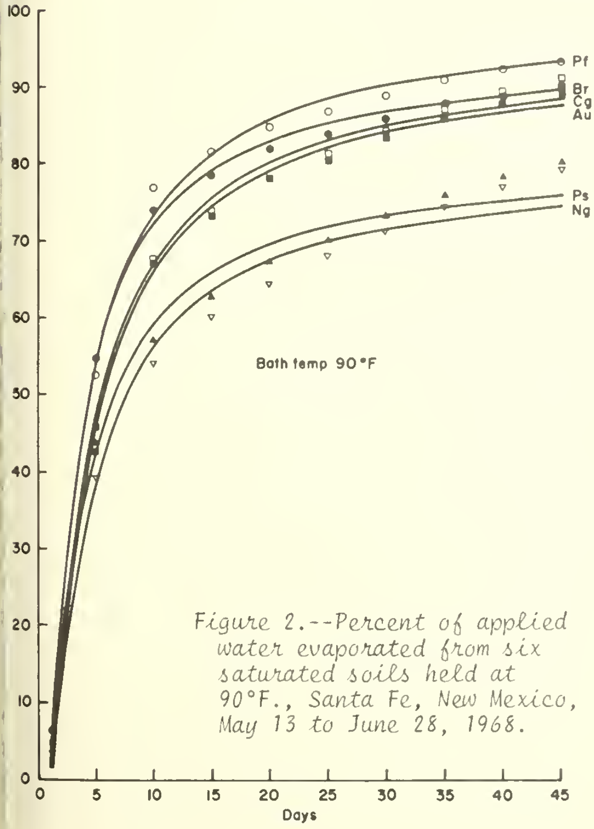

Figure 2.--Percent of applied water evaporated from six saturated soils held at 90°F., Santa Fe, New Mexico, May 13 to June 28, 1968.

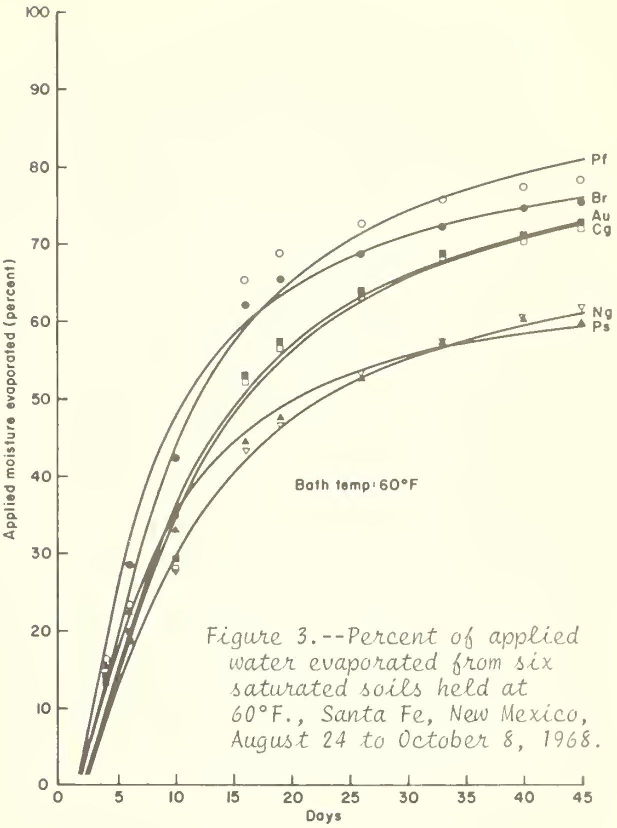

Figure 3.--Percent of applied water evaporated from six saturated soils held at 60°F., Santa Fe, New Mexico, August 24 to October 8, 1968.

evident in the fall run. These data fit the concept of evaporation from bare soil discussed by Philip (1964) and Gardner and Hillel (1962).

The percentage of applied water which evaporated was fitted to the model:

$$Y = Ae^{-B/t} \qquad [1]$$

where

Y = percentage of water evaporated
t = time in days
B = drying time lag coefficient
A = the ultimate equilibrium drying moisture content

Values of A and B for the six soils and correlation coefficients under three drying conditions are shown in table 2. Ideally, A values should be 100 percent. This point was not actually reached under diurnally fluctuating atmospheric conditions, however, even after many weeks of drying. The rate of change of drying may be expressed mathematically by the differential equation:

$$\frac{dY}{dt} = \frac{BAe^{-B/t}}{t^2} = \frac{BY}{t^2} \qquad [2]$$

Table 2.--Values of A and B in equation 1, and regression coefficients for each of six Rio Puerco soils under drying conditions. Santa Fe, New Mexico, 1968

Soils	May-June, 90°F.			May-June, 60°F.			Aug.-Oct., 60°F.		
	A	B	r	A	B	r	A	B	r
Br	95.47	2.778	0.998	90.30	4.275	0.994	86.60	5.916	0.982
Pf	99.94	2.959	.996	96.24	5.008	.992	96.30	7.790	.979
Au	94.98	3.621	.997	88.84	5.624	.994	89.23	8.971	.985
Ps	81.73	3.175	.995	71.23	4.036	.997	69.15	6.552	.983
Cg	95.75	3.520	.997	89.47	5.676	.995	89.76	9.420	.985
Ng	80.70	3.582	.993	68.44	4.520	.997	75.03	9.146	.979

Thus rate of change of drying at any point in time may be calculated from the curves of figures 1-3.

With minor exceptions, the evaporation data fit the theoretical model quite well, as shown by the consistently high correlation coefficients. Some adjustment downward should be made, because the curves are made to pass through the origin.

Atmospheric conditions (wind, temperature, and radiation) markedly affected evaporation rate, particularly when the soils were wet. The initial rate of water loss in mid-May from the pots in the 60° F. water bath was about double the rates from the same pots and bath in late August through October, when daily atmospheric stresses were appreciably less.

Some evidence of soil structural change was apparent between the curves in figures 1 and 3 for the Persayo and Navajo soils. The Navajo clay shrunk and cracked appreciably upon drying and tended to aggregate, while the Persayo soil did not. The result was a convergence of the drying curves of the two soils in the second run. This phenomenon of changing structure with successive wetting and drying was discussed by Gardner and Hanks (1966).

Laboratory Drying Experiment

Procedure.—The second experiment was run in the laboratory with the same six soils. Samples were passed through a crusher to break down clods, and were then placed in plastic-lined containers 6 inches in diameter by 4 inches deep. Twenty-five hundred grams of air-dry soil was placed in each container. Each of the six soils was replicate four times.

The temperature in the laboratory was mai tained at 83° F. ± 3° with a fan to increase ai circulation.

Successive applications of 0.1, 0.2, 0.5, an 1 inch of water were added to all pots and allowe to evaporate.

Results.—When increments of 0.1, 0.2, and 0. inch of water were applied to the surface of th six soils, differences in evaporation rates amon soils were negligible (fig. 4). With the exceptio of the 1-inch application, the differences in eva orative loss among soils were not statistically sig nificant until over half of the applied water wa gone, as measured by an analysis of variance c periodic accumulative moisture loss. The Navaj soil showed a tendency to dry more slowly tha the other five soils. At the same time, the sand soils, Berent and Penistaja, lost their moisture mor quickly than those with finer texture, although th variation was slight. However, differences betwee these two soils and the others were large onl from the 1-inch application. It appears that eva orative demand was the primary controlling energ factor when small increments of water were adde and moisture transmission and heat flux were min or negligible. With the 1-inch application, effec of moisture transmission and possibly heat flu increased.

Under these mild stress conditions, approximatel half the 0.1, 0.2, and 0.5 inch increments of wate evaporated from all pots in 8, 24, and 72 hour respectively. When 1 inch of water was applie

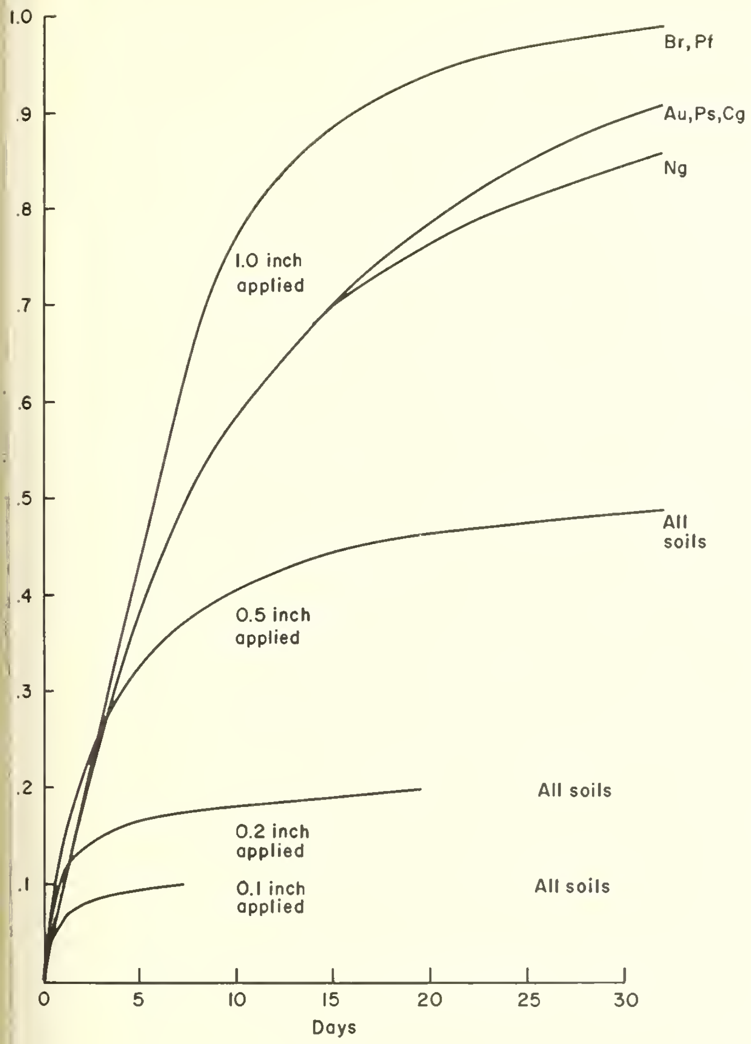

Figure 4.--Inches of water evaporated from six soils to which had been applied 0.1, 0.2, 0.5, and 1 inch of water. Soils were on laboratory table at 83°F.

out half of it evaporated in 4.5 days from the ndy soils compared to 7 days for the finer tex- red soils.

Roof Experiment

Procedure.—In a third experiment, Penistaja, ristianburg, and Navajo soils were potted in ntainers used in the second experiment. Water s added in 0.5-, 1.0-, and 1.5-inch increments. ch of these water-soil treatments was replicated ree times. The pots were then exposed to the mosphere on a graveled roof from May 26 to ne 6, where the daily maximum and minimum mperatures averaged 91° and 59° F., respectively.

Results.—Evaporation curves for two soils only are shown (fig. 5). When 0.5 inch of water was added, the evaporation curves of the two soils (Penistaja loam and Navajo clay) were very similar. Differences in evaporation from the two soils increased as the amount of water applied increased, which indicates an increasing effect of soil moisture transmission and heat flux as the increment of applied water increased.

Discussion

Data from these studies indicate that evaporation from soil was strongly influenced by soil temperature. When soils were held at 60° F., water from wet soil

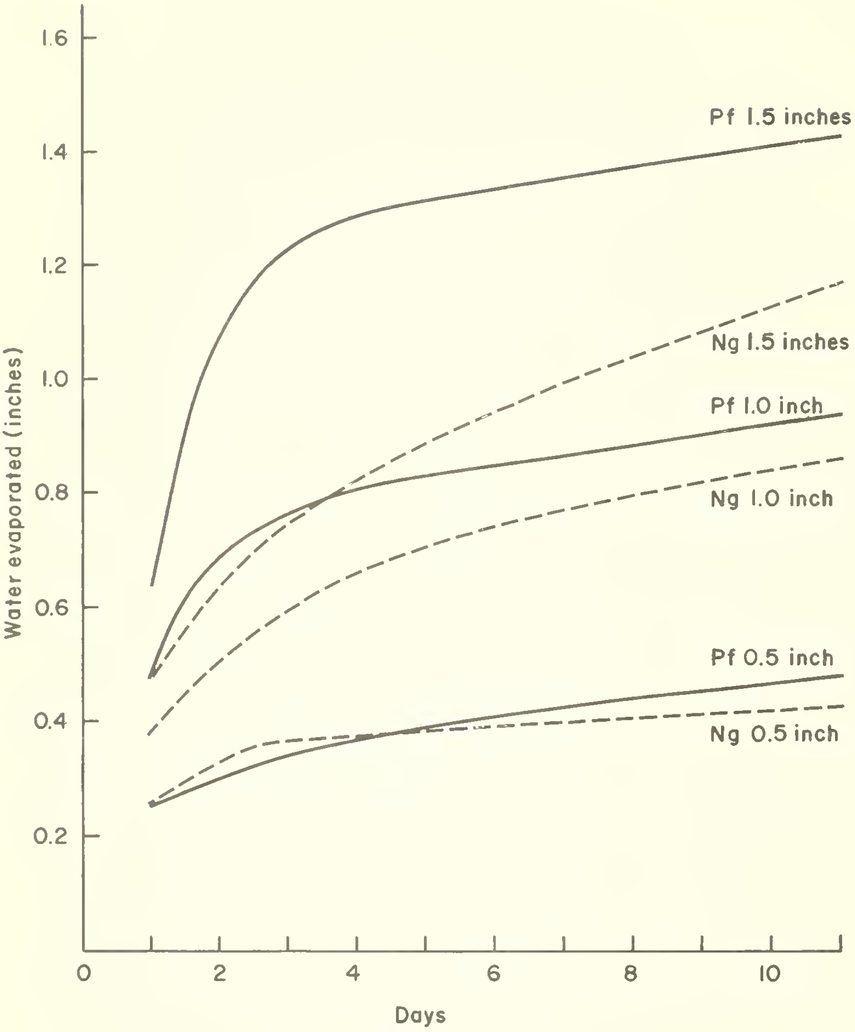

Figure 5.--Inches of water evap rated from two soils to which had been applied 0.5, 1.0, an 1.5 inches of water. Soils were exposed to open atmosphere with average daily maximum temperature of 93°F. and daily minimum of 59°F.

(first week of drying from saturated) evaporated at 0.22 inch per day as compared to 0.33 inch per day from soil held at 90° F.

Evaporation rates were also strongly influenced by atmospheric conditions, including air temperature, wind, and radiation. Although these factors were not documented, day-to-day fluctuations in weather had a noticeable effect on evaporation. Soils in the 60° F. bath lost water by evaporation almost twice as rapidly in May-June as in August-September-October.

When soils were saturated, sandy soils lost half their moisture by evaporation in 5 days at 90°F. and 7 days at 60°F. compared to 8 and 15 days for Navajo clay under similar conditions.

Interpretation of the data is complicated by complex environmental conditions and by the limited data. Moisture profiles were not followed as drying progressed, so only limited interpretation of successive soil weights is possible.

In the first drying of soils from saturation, -1/3 bar mean potential was reached (using equation 1 in the Navajo clay in 4.3 days at 90° F. and in 6.5 days at 60°F. On the other extreme, the Penistaja sandy loam reached -1/3 bar potential in 10 days at 90° F. and 19.3 days at 60° F. The other soils ranged between these extremes.

If equation 2 is applied to these points, the Penistaja soil was losing 2.1 percent of applied moisture per day at 90°F. and 1.0 percent per day at 60°F.; Navajo clay was losing 6.6 percent per day at 90° F. and 3.6 percent per day at 60° F The implication of these calculations is that sandy soils lose moisture from the surface rather rapidly comparison to clay, but a moisture barrier is rmed by the dried surface soils, and the suburface potential changes more slowly than in the ay.

These findings are limited in field application situations where there is negligible internal drainge. If the internal drainage were unrestricted, e sandy soils would reach -1/3 bar potential more uickly than the clay.

Although the rate of moisture loss was less om the sandy soils at -1/3 bar than from the ay at the same mean potential, the sandy soil ad only 4 percent moisture by weight to lose efore reaching the -15 bar potential, whereas the ay soil had 19 percent more moisture by weight t -1/3 bar: than at -15 bars.

Initial evaporation rates were nearly the same r all these soils when small increments of water ere applied. By the time half of a 1-inch applicaon had evaporated, however, considerably lower vaporation rates were evident in the finer-textured ils than in the sandy soils.

Here again the differences among soils are tributable to energy relations. The clay soils, ecause of their greater water-holding capacity, eld that water with greater force than did the ndy soils. For example, 1 inch of water was ore than enough to wet the entire container of enistaja fine sandy loam, but only wet the Navajo il to about 1.8 inches deep. Upon drying (fig. 5) e Penistaja soil reached -15 bars potential in days, as compared to 2 days for the wetted poron of the Navajo clay. Half an inch of water wet e entire container of Penistaja, but wet the avajo clay only to 0.9 inch. The Penistaja sandy am soil dried to -15 bars potential in 2 days, hile the wetted Navajo clay reached -15 bars tential in less than 1 day.

These projections gain relevance when we conder that the average summer convective storm the San Luis experimental watershed deposits ss than 0.3 inch of water. A storm which preitates over 1.5 inches occurs about once every years. These large storms often occur in the fall and extend over a 2-day period.[2] Sufficient time usually elapses between the summer storms for the soil to dry out.

On the basis of these studies and in view of the prevailing weather patterns, it becomes evident that the amount of moisture received from precipitation alone is not enough to maintain adequate soil moisture conditions for range grass germination and seedling establishment. Additional moisture contributed as runoff from adjacent areas is required.

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U S D A FOREST SERVIC
RESEARCH NOTE RM-191

Y MOUNTAIN FOREST AND RANGE EXPERIM

Height-Diameter Equations for Arizona Mixed Conifers

R. S. Embry and G. J. Gottfried[1]

Relationships between total height and diameter breast high in Arizona virgin mixed conifer stands may be expressed by the equation log (H - 4.5) = b log D + c (log D)^2.

KEY WORDS: Tree volume measurement, stand increment estimates, mixed conifer forests

The relationship of diameter at breast height to some measure of tree height has several applications in forest mensurational problems. One of the most familiar is in the derivation of local volume tables from standard volume tables. The height-diameter relationship may also be used to describe stands and stand development over a period of time, to estimate mean heights of specific portions of a stand, and in the estimation of growth by stand projection methods.

The purpose of this study was to develop equations that would express the height-diameter relationship for the Arizona mixed conifer species.

Data

Total height-diameter data were obtained from an inventory of 1,800 acres of virgin mixed conifer forests on the Apache National Forest in east-central Arizona. A total of 556 permanent plots were sampled.

The sample-tree data represented a wide range of diameters and heights for all of the eight commercial species in these mixed stands (table 1).

Table 1.--Number and range of measurements of sample trees

Species	Sample size	Diameter range	Height range
		Inches	Feet
Engelmann spruce *(Picea engelmannii)*	118	2-36	10-125
Blue spruce *(Picea pungens)*	23	2-26	11-124
Corkbark fir *(Abies lasiocarpa* var. *arizonica)*	24	8-34	47-125
Douglas-fir *(Pseudotsuga menziesii)*	278	2-51	11-148
Ponderosa pine *(Pinus ponderosa)*	172	3-40	17-145
White fir *(Abies concolor)*	152	2-49	12-134
White pine *(Pinus strobiformis)*	99	2-44	12-130
Quaking aspen *(Populus tremuloides)*	121	3-26	22-110

Equations Considered

Because it is desirable that the H/D curve include the entire range of diameters, a curve passing through the point of origin (0, 4.5) was required. Curtis[2] suggests three equations for sigmoid curves that would meet this requirement:

$$\log (H - 4.5) = a + b D^{-1}$$
$$\log (H - 4.5) = a + b \log D$$
$$\log (H - 4.5) = a + b \log D + c (\log D)^2$$

where: H = total height in feet; D = diameter breast high in inches; and a, b, and c are regression coefficients. The "a" coefficient must be zero for these equations to pass through the origin.

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[1] *Embry is located at Flagstaff in cooperation with Northern Arizona University; Gottfried is at Tempe in cooperation with Arizona State University. Station's central headquarters is maintained at Fort Collins in cooperation with Colorado State University.*

[2] *Curtis, Robert O. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. Forest Sci. 13: 365-375. 1967.*

Regressions of form corresponding to each of these equations were fitted to the eight sets of measurements and to two sets of combined measurements. The species combined were: (1) Engelmann spruce, blue spruce, and corkbark fir, and (2) Douglas-fir and ponderosa pine.

Four other equations tested gave unsatisfactory estimates of heights for the small diameter trees:

$$H = a + b\,D + c\,D^2$$
$$H = 4.5 + b\,D + c\,D^2$$
$$H = a + b \log D$$
$$H = 4.5 + b \log D$$

Results

The height-diameter relationship was best expressed by the equation of form:

$$\log\ (H - 4.5) = b \log D + c\ (\log D)^2$$

Because the regressions for Douglas-fir and ponderosa pine were not significantly different, a single equation is recommended for them. A single equation is also recommended for Engelmann spruce, blue spruce, and corkbark fir.

The regression equation fitted the basic data very well (table 2).

Heights for each species or combination species were calculated by 2-inch d.b.h. inte vals over the range of diameters that migh normally be found in these mixed stands (tabl 3).

Because the "c" regression coefficients ar negative, the calculated heights will reach maximum at some large diameter, and the decrease for diameters above this point. Whe this occurs, the maximum height should b repeated for all subsequent diameters.

Table 2.--Statistics for the calculated regression equations

Species	Regression coefficients b	Regression coefficients c	$S_{y \cdot x}$	R^2
Engelmann spruce, blue spruce, and corkbark fir	2.5390	-0.7908	10.6	0.9
Douglas-fir and ponderosa pine	2.4096	- .7144	11.4	.9
White fir	2.3388	- .6830	9.2	.9
White pine	2.4773	- .8035	12.3	.9
Quaking aspen	3.0275	-1.2125	10.0	.9

Table 3.--Total heights (feet) of Arizona mixed conifer species

Diameter breast height (Inches)	Engelmann spruce Blue spruce Corkbark fir	Douglas-fir Ponderosa pine	White fir	White pine	Quaking aspen
2	9	9	9	9	11
4	22	20	19	20	29
6	36	32	30	32	46
8	49	44	40	43	60
10	60	54	50	52	70
12	70	63	58	59	76
14	79	71	65	65	80
16	86	78	72	70	82
18	92	84	77	74	[1]82
20	97	89	82	77	82
22	101	93	86	80	82
24	104	97	89	82	82
26	107	100	92	83	82
28	109	102	94	84	
30	110	105	97	85	
32	112	106	98	86	
34	113	108	100	86	
36	113	109	101	[1]86	
38		110	102	86	
40		111	103	86	
42		111	104	86	
44		112	104	86	
46		112	105		
48		112	105		
50		[1]112	105		
52		112			

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[1] Diameter at which the calculated height reaches a maximum.

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RESEARCH NOTE RM-192

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

A Comparison of Aerial Photo and Ground Measurements of Ponderosa Pine Stands[1]

Frederic R. Larson,[2] Karl E. Moessner,[3] and Peter F. Ffolliott[4]

All ground estimates of cubic-foot volume and basal area were significantly correlated with photo estimates. Differences in results due to plot size (1/5 or 1 acre) or photo scale (1:15,840, 1:6,000, or 1:3,000) were minor, and any combination of plot size and photo scale tested was satisfactory. The 1/5-acre plots on 1:6,000-scale photos were the most efficient to measure, however.

KEY WORDS: Pinus ponderosa, aerial photography, forest surveys

Introduction

High-quality, large-scale aerial photographs offer a source of specific information on large areas. Timber volume, density, and certain site factors can be estimated efficiently on aerial photos, but estimates must be localized by on-the-ground sampling. In this study we evaluated the relationship between aerial photo and ground estimates of ponderosa pine (Pinus ponderosa Laws.) cubic-foot volume and basal area per acre, aspect, and slope steepness on panchromatic contact prints with photo scales of 1:3,000, 1:6,000, and 1:15,840.

Study Area

The study area included approximately 2,000 acres of cutover, uneven-aged ponderosa pine stands on the Beaver Creek Watershed (Worley 1965) in Arizona. About 85 percent of the overstory volume was ponderosa pine and 15 percent woodland species, primarily Gambel oak (Quercus gambelii Nutt.) and alligator juniper (Juniperus deppeana Steud.).

Ponderosa pine averaged 2,000 cubic feet volume and 110 square feet basal area per acre. Timber was last harvested from 1943 to 1950, when one-half of the merchantable volume was removed. The average site index (Meyer 1961) was 60 feet at 100 years of age.

Methods

Three photo flights were made over the study area to obtain photo scales of 1:3,000, 1:6,000, and 1:15,840. A Zeiss[5] Aerial Photo camera was used with a focal length of 8-1/4 inches. Kodak Plus X Panchromatic film was exposed through a minus blue filter at 1/500th of a second and at stop f-8.

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[1] *This study was supported in part by funds provided by the U. S. Department of the Interior as authorized under the Water Resources Research Act of 1964, Public Law 88-379.*

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[5] *Trade and company names are used for the benefit of the reader and do not imply endorsement of preferential treatment by the U.S. Department of Agriculture.*

A 9-dot-per-square-inch grid was overlaid on 1:15,840 photos, and grid points were stratified by aspect as warm (SE, S, SW, W), cool (NW, N, NE, E), or flat, and by slope steepness (0-9, 10-19, or 20+), and crown cover (0-19, 20-39, 40-59, 60+) in percent. One grid point was picked at random from each stratum, and to reduce travel time a cluster of three plots was located around that point. The grid point was the center of the middle plot, and two other plot centers, located along the contour, were staked on the ground and pinpointed on photos for each scale (fig. 1). Seventy-five potential study plots were located, but some were eliminated because of open areas or lack of stereo photo coverage.

Photo estimates were made by Moessner on 1/5- and 1-acre circular plots with the center oriented over the grid point. For the dominant stand, average total height, determined from parallax wedge measurements, and crown cover percent, determined by comparing plots with a crown density scale, were measured on all three photo scales, and volume estimates read from an aerial volume table (Moessner 1963). The basal areas were obtained in the same manner (Moessner 1964a), except that measurements of the understory were included. Aspect (45 degrees) and slope steepness (5 percent) were determined by scale line orientation and parallax measurements (Moessner 1964b).

Ground cubic-foot volume (Myers 1963) and basal area per acre were estimated on five points by standard point sampling techniques The five points were within a 1/5-acre plot Aspect (45 degrees) was determined from compass readings and slope steepness (5 percent) was measured with a clinometer at the five points and averaged.

Analysis of Results

Linear regression was used to determine the association between photo and ground estimates of cubic-foot volume and basal area (table 1). The range of data for ground estimates was 381 to 4,847 cubic feet and 15 to 220 square feet basal area per acre.

Results were not significantly different between plot sizes. Correlation coefficients developed for different photo scales were similar within a plot size but slightly higher for 1/5-acre plots. Aerial photo estimates were greater than ground estimates in all cases, as indicated by regression coefficients less than one. A focal length of 8-1/4 inches was used, which resulted in easily obtained estimates on 1:6,000 photos due to the ground detail and tree tops which could be seen under a lens stereoscope Differential parallax was less than 0.1 inch for the tallest trees. Ground features could be

Figure 1.--
A portion of the stud
area shown on three
aerial photos with
scales of 1:15,840,
1:6,000, and 1:3,000,
respectively.

Table 1.--Regression equations of ground versus photo estimates of cubic-foot volume and basal area per acre

Plot size and aerial photo scale	Cubic-foot volume			Basal area		
	Intercept (a)	Slope coefficient (b)	Correlation coefficient	Intercept (a)	Slope coefficient (b)	Correlation coefficient
1 acre:						
1:3,000	448.7	0.822	0.61	4.99	0.824	0.71
1:6,000	777.8	.754	.44	27.43	.737	.66
1:15,840	150.4	.901	.59	8.66	.776	.70
1/5 acre:						
1:3,000	699.8	.827	.72	20.49	.906	.80
1:6,000	750.5	.933	.75	35.58	.797	.74
1:15,840	678.1	.848	.68	28.04	.852	.78

eadily seen on 1:3,000 photos, but displacement of tree tops due to differential parallax from 0.15 to 0.17 inch) made measurements ifficult. Also on the largest scale photos, imbs and branches became visible and the nterpreter had more difficulty placing his arallax mark on the tallest part of a tree. 'he 1:15,840 photos did not have the resolution r visible detail found on the two larger scale hotos. The smaller plot size on 1:6,000-scale hotos was the most efficient to measure.

Of the 430 estimates, 262 (60.9 percent) greed within one aspect position (45 degrees) nd one slope classification (5 percent) (fig. 2).)f these, 180 (41.9 percent) aspects and 130 30.2 percent) slopes were recorded correctly, nd in 55 cases (12.8 percent) both aspect and lope agreed with ground estimates. The agreement of estimates was best on 1:6,000, intermediate on 1:3,000, and poorest on 1:15,840, lthough differences were minor. Estimates or 1/5-acre plots were slightly better than iose for 1-acre plots.

An analysis of the plots which agreed within ne aspect position and/or one slope steepness assification revealed an apparent bias to throw hoto plots one aspect position in a clockwise irection. This may be due to photo interreter preference, wrong aspect for a photo :ale line, magnetic attraction in the area causıg errors in ground readings, or a combination the above. The number of slope estimates hich were too steep about equaled the number f estimates which were too shallow. Steep opes were underestimated, however, and iallow slopes were overestimated. This may e due to the relatively shallow slopes in the rea, and rounding data to the nearest 5 percent classifications. Results would probably e better in areas with greater relief.

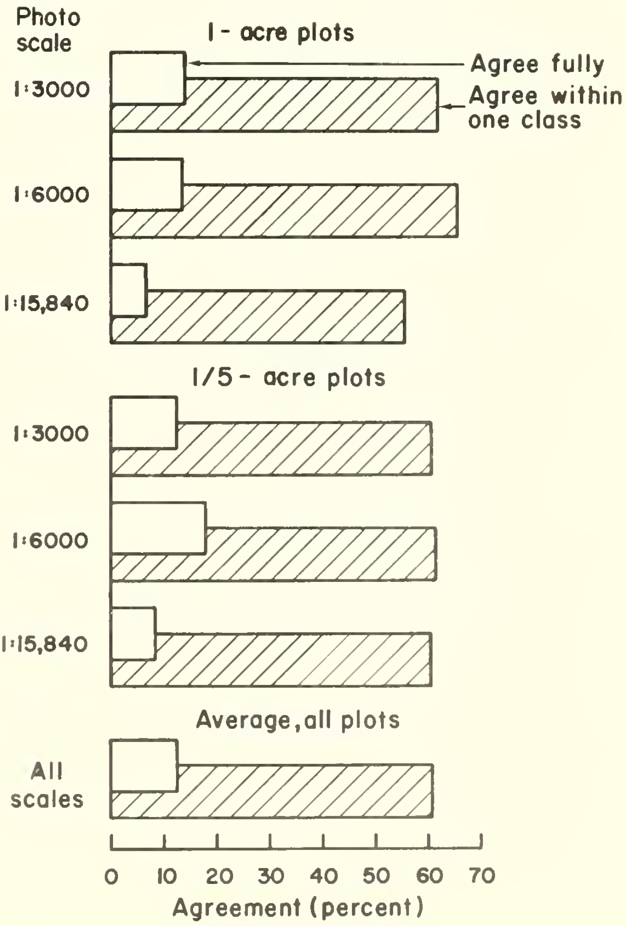

Figure 2.--Percent of photo plot estimates that agree fully with ground estimates, or agree within one classification (aspect, 45°; slope steepness, 5 percent).

All ground estimates were significantly correlated with photo estimates. This implies that extensive inventories of timber volume and density, slope percent, and aspect can be derived from measurements of aerial photos with on-the-ground field sampling for localizing and prorating photo estimates. Small scale (1:15,840) photos were adequate for this study. For small areas, however, a larger photo scale (1:6,000) may be more desirable and slightly more accurate if better resolution is needed for other purposes. No advantage was gained at a larger scale of 1:3,000.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-193

ST SERVICE
DEPARTMENT OF AGRICULTURE

MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

A Recording Gage for Blowing Snow

Ronald D. Tabler and Robert L. Jairell[1]

A rotating recording gage to sample the horizontal mass flux of blowing snow was devised by attaching a snow trap to a recording precipitation gage mounted on a turntable. Two years of experience has shown the record to be useful for determining windspeed thresholds of blowing snow, for comparing relative amounts of drifting snow at different locations, and for determining the source of blowing snow at snow fence sites.

KEY WORDS: Blowing snow gage, snow transport, mass flux, snow trap, drifting snow.

In many areas of the West, blowing and fting snow produce hydrologically important ow accumulation patterns. Research or nagement programs involved with the water ource in such areas would often benefit from asurements of the amount, or horizontal ss flux, of blowing snow. The determination total snow transport over an interval of time esents extreme technical difficulties and, for ny purposes, the effort required to obtain necessary data cannot be justified. Useful ormation on the time distribution and **relative** ensity of snow transport, however, can be dily obtained from a continuous record of horizontal mass flux at some constant ght in the first meter above the ground.

Many varieties of snow traps and particle inters have been used to sample snow movent over relatively short periods of time, t a need remains for a simple, inexpensive ow trap that can record, unattended, the movement of windblown snow over a period of days or weeks. In our research program with snow fences, for example, it is necessary to know windspeed and direction for each blowing-snow event. To obtain such data, a snow trap, modified from an existing design used in the Antarctic, was mounted on a Belfort[2] recording precipitation gage. Two years of experience with this device has shown it to be satisfactory for metering the horizontal mass flux of blowing snow on our site at 8,500 feet elevation in southeastern Wyoming.

Snow-trap Design

We chose to use the rocket-type snow-trap configuration proposed by Mellor[3] because it is reported to be relatively efficient, and can be adapted for mounting on a precipitation

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[2] *Trade and company names are used for the benefit of the reader, and their use does not constitute endorsement or preferential treatment by the U.S. Department of Agriculture.*

[3] *Mellor, Malcolm. Blowing snow. Cold Regions Res. and Eng. Lab., Cold Regions Sci. and Eng. Part III, Sect. A3c. p. 13. 1965.*

gage. There are no internal baffles that might reduce air intake; snow particles settle out because air speed is reduced in an expanded internal flow section with a maximum area about 436 times that of the intake. The exhaust orifice is 10 times larger than the intake.

Mellor's design was modified to permit a larger sample of air to pass through the gage. To collect an amount of snow that would be discernible on a recording precipitation gage chart, at a sampling height of 0.5 to 1 meter above the ground, the intake orifice area was increased about tenfold, to 3.142 cm^2. The exhaust orifice and stilling section areas were also increased by a factor of 10. To keep the trap small enough to permit attachment to a precipitation gage, the stilling section length was kept at 8 inches, and the lengths of the intake and exhaust transitions were scaled to be in about the same proportion to the stilling section diameter as in Mellor's design (fig. 1). It was hoped that, with these compromises in the enlargement, the collection efficiency of the original design could be retained.

The intake and exhaust orifices are made from commercially available copper pipe and fittings. Both orifices are screwed into fittings soldered or welded to the gage body so that damaged orifices can be easily replaced in the field. The collar at the bottom of the stilling section is designed to fit snugly inside the 8-inch precipitation gage orifice. The snow trap is fastened to the precipitation gage with two heavy duty suitcase latches.

The snow trap in figure 1 was fabricated in 1969 by a local sheet-metal firm at a cost of $86.

In field use, we have not observed snow, ice, or rime accumulations in the orifices which would affect gage catch. At higher elevation sites, however, rime deposits might present problems.

During two events over the last two winters, significant snow accumulated inside the snow trap without being deposited directly in the precipitation gage bucket. These events were indicated by a sudden rise on the chart as warm air and sun melted this snow. We do not know yet what conditions of snow and wind cause deposition within the trap itself.

Rotating Platform

To allow the snow trap to aline itself with the wind, the precipitation gage is bolted to a rotating platform, or turntable, fabricated from an automobile front-wheel-bearing assembly (Chevrolet, 1940 to 1954, fig. 2). The turntable assembly fits on a splined shaft, set in concrete, that supports the gage. This permits the recording gage and rotating platform to be

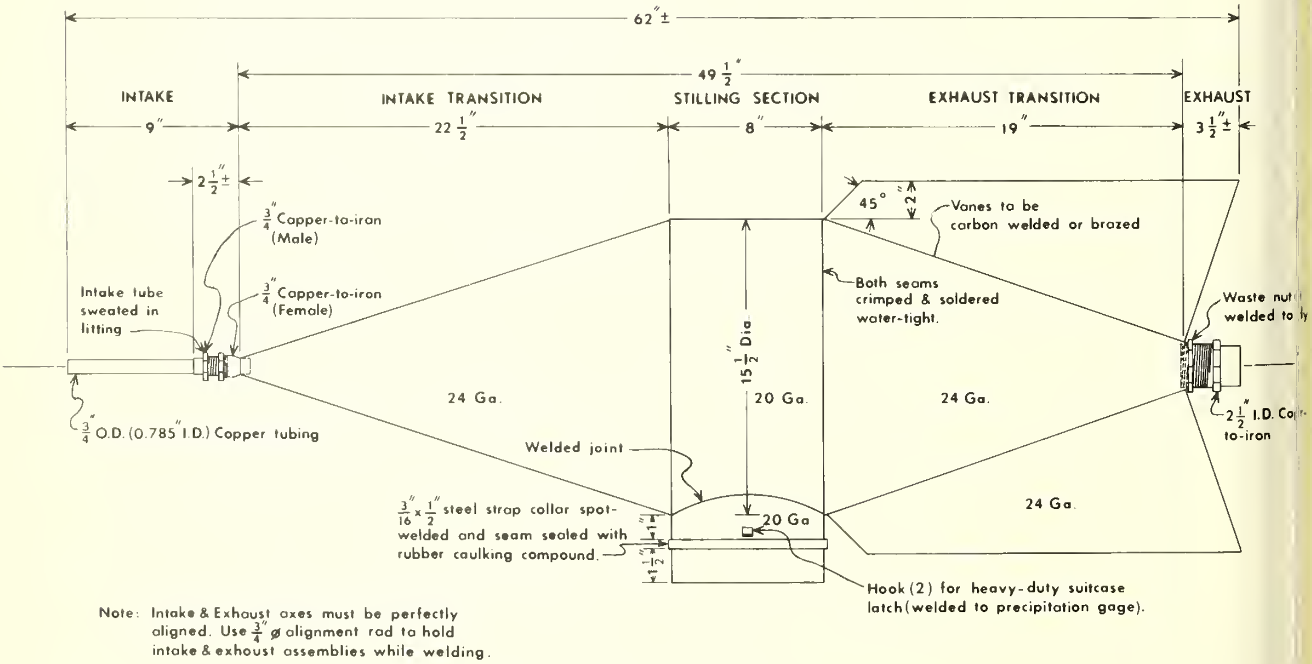


Figure 1.--The snow trap, as modified from Mellor's (Mk III) design.

ɹe 2.--Rotating turntable which
ɪpports the blowing snow gage.
ɪe bearing assembly is fabricated
ɾom an automobile front wheel-
ɛaring. The entire platform,
ɪth gage attached, can be lifted
ɾom the base support to permit
ɛrvicing when the gage is
ɪstalled in a pit.

. 1/4-inch steel plate, 15
inches in diameter, for
mounting gage.

. Front wheel-bearing
assembly.

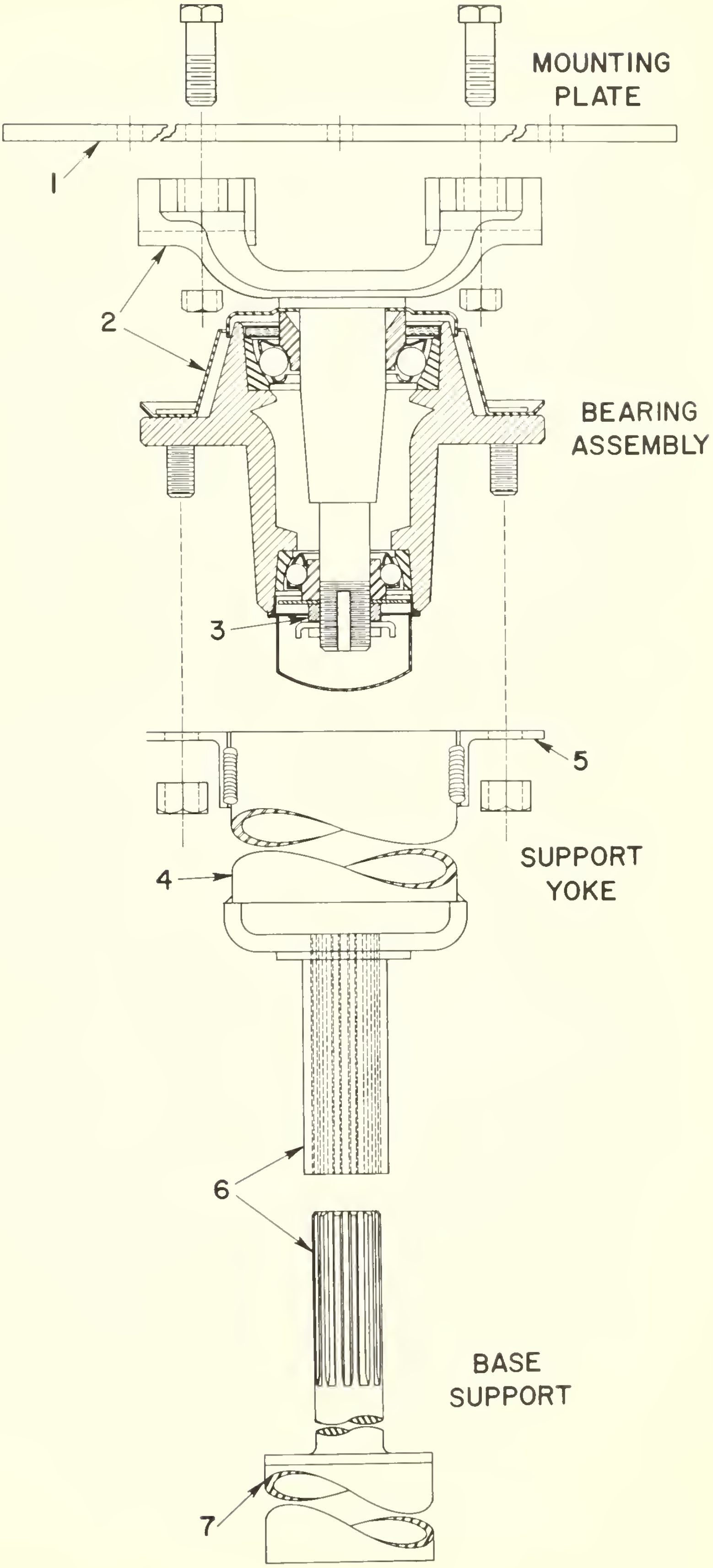
. Wheel-bearing adjusting
nut.

. Steel pipe, 3 inches I.D., 4
inches O.D., welded to U-
joint.

. Three pieces of 1/8-inch angle
iron, 1-1/4 by 1-1/4 inches,
welded to pipe for attaching
support yoke to bearing
assembly.

. Matching automobile drive line
and universal-joint yoke.

. 18 inches of drive line below
splines to be set in concrete.



removed as a unit to facilitate servicing when the gage is installed in a pit for low-level measurements.

With proper adjustment of the wheel-bearing nut, it is possible for the gage to orient itself under a windspeed as light as 5 miles per hour, without allowing play in the bearings that can cause excessive vibrations of the precipitation gage pen-arm linkage. A certain amount of vibration in the gage is unavoidable, however, with strong or variable winds. To reduce the vibration transmitted to the pen-arm, a small piece of rubber was substituted for the metal calibrating slide (fig. 3). This modification requires some adjustment and recalibration of the precipitation gage weighing mechanism.

To insure that the turntable will turn easily even in subfreezing temperatures, the bearing assembly is packed with silicon grease.

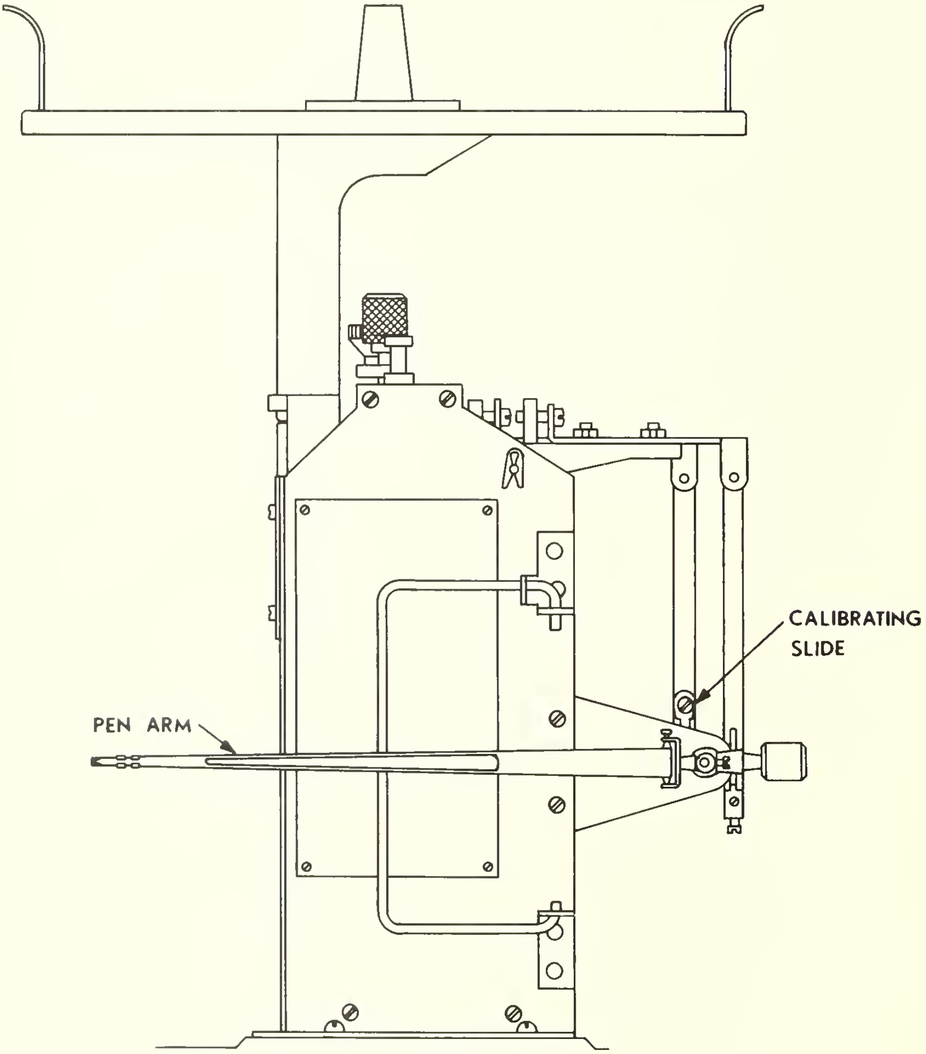


Figure 3.--A portion of the pen-arm reversal linkage on a Belfort No. 5-780 recording rain gage. A small piece of rubber was substituted for the metal calibrating slide, to reduce wind-induced vibration at the pen.

Field observations have shown the snow p's alinement with the wind to be quite ady over the range of windspeeds typical our study area. This is attributed to the ge moment of inertia of the gage, and the ge surface area of the snow trap, which mbine to stabilize the gage against the more pid fluctuations in wind direction.

Installation

The gage should be installed on a level, en site, free of excessive snow accumulation, prevent the base of the gage from being ried in snow that might interfere with rotation. A majority of drifting events on our site not have sufficient snow movement at heights 1 meter and above to result in a large ough catch to be discernible on the recording art. For this reason, we have installed one ge in a pit, with the orifice at a height of meter (figs. 4,5). This is about the lowest el that will maintain sufficient clearance between the snow trap and the snow surface. The turntable assembly was designed so that the entire assembly could be lifted out of the pit for servicing.

We have installed some gages so that the entire device is aboveground, with the intake orifice between 1 and 1.2 meters aboveground (fig. 6). This has proved to be about the maximum height at which sufficient snow can be collected during major drifting events to be discernible on the recording chart.

There are four main advantages of the pit installation over that of an aboveground gage. First, because snow catch at 0.5 meter is much greater than at 1 meter, detection and analysis of drifting events are improved. Second, the greatest part of the gage is sheltered from the wind, substantially reducing pen-arm vibration. Third, the pit prevents blowing snow from entering the weighing, recording, and clock mechanisms. Fourth, burying the precipitation gage makes the total installation more streamlined, with less disturbance of the airflow.

Figure 4.--The blowing-snow gage, with turntable attached, can be lifted out of a pit for servicing.

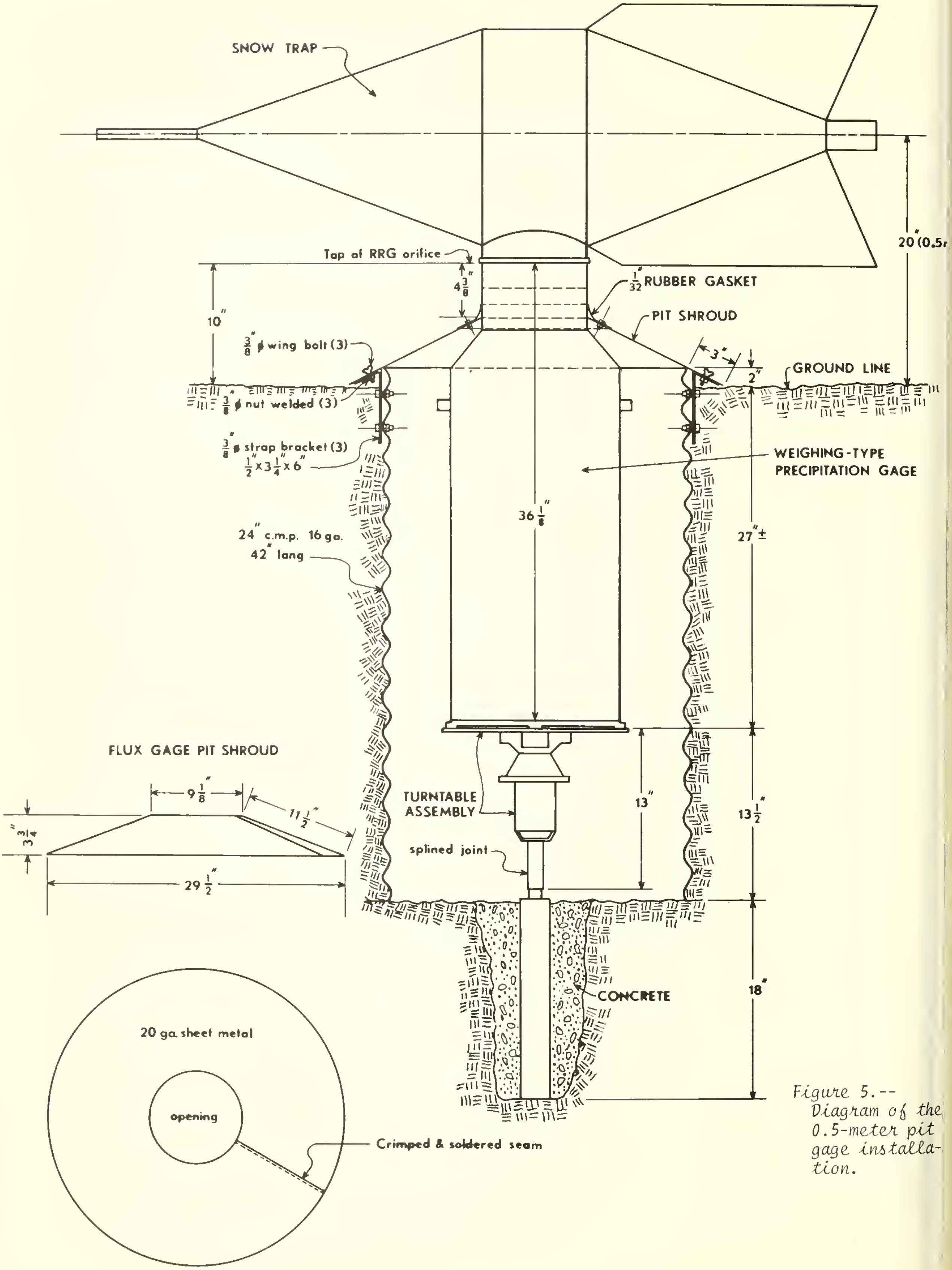


Figure 5.--Diagram of the 0.5-meter pit gage installation.

ıre 6.--
lowing-snow
ıges installed
ith orifice
ights of 1
ıd 0.5 meter
oveground.

Applications

No attempt has yet been made to calibrate s modified snow trap with other gages and rices presently in use; this will have to be ne before the gage catch can be considered thing more than an index to snow transport. ere are many uses for the record obtained m this gage, however, without calibration or standardization. The quality of the chart record (fig. 7) is such that catch rates and amounts can be correlated with windspeeds and directions from a nearby anemometer. We are using such data to determine windspeed thresholds for blowing snow, for comparing relative amounts of drifting snow at different locations, and for determining the source of blowing snow at snow fence sites.

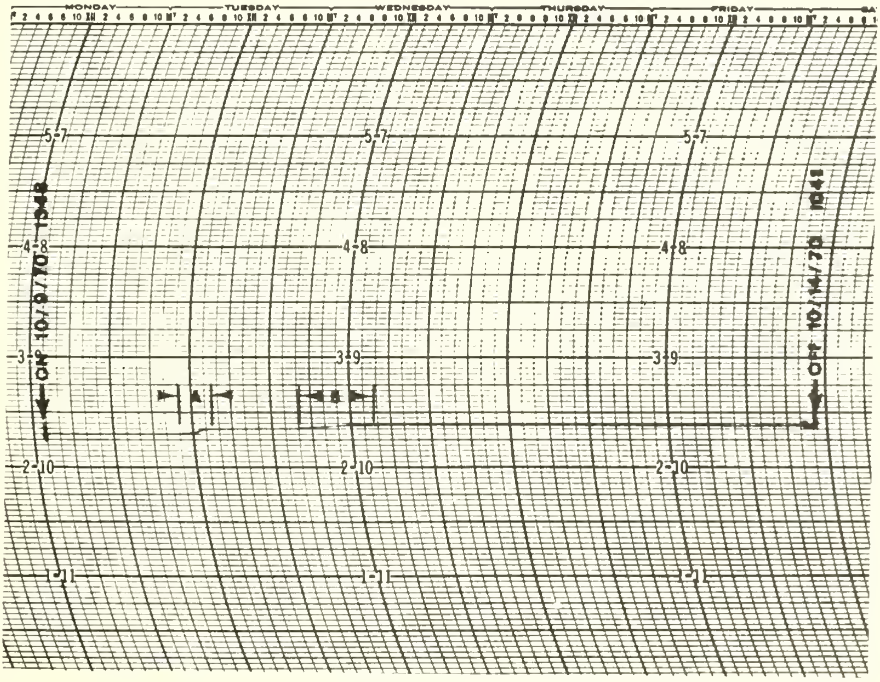


Figure 7.--Reproduction of an actual record obtained from the 0.5-meter gage. The two drifting events are marked A and B.

U S D A FOREST SERVICE
RESEARCH NOTE RM-194

REST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Western Pine Tip Moth Reduced in Ponderosa Pine Shelterbelts by Systemic Insecticides

David F. Van Haverbeke,[1] Robert E. Roselle,[2]
and Gary D. Sexson[2]

A spring application of 40 grams of phorate granules (Thimet 15G) raked into the soil beneath the tree crown effectively protected young ponderosa pine in a Great Plains shelterbelt from damage by western pine tip moth for two growing seasons. Dimethoate (Cygon^{267}) sprayed in the spring and summer provided immediate control of the tip moth during the first larval generation but not the second. Data suggests precise timing of dimethoate application to emergence of larval stage is necessary, and that it has less carryover effect than phorate.

KEY WORDS: *Pinus ponderosa*, *Rhyacionia bushnelli*, phorate, dimethoate, insecticides.

The Problem

Ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) has been used since pioneer days in protective tree plantings on the Great Plains. It was the most widely used pine species in the shelterbelts and windbreaks planted throughout the central and northern Great Plains during the Prairie States Forestry Project of the late 1930's and early 1940's. Even more conifers are being used currently in protective tree barriers in the central Great Plains, and ponderosa pine is one of the most widely planted species.

Ponderosa pine is susceptible to attack, however, by the western pine tip moth (*Rhyacionia bushnelli* Busck) (Lepidoptera: Olethreutidae) (Miller 1967). Damage by this insect was reported in young ponderosa pine soon after the first plantations were established in early 1900's on the Nebraska National Forest in the Sandhills grasslands. This pest is now likely to be found in practically all shelterbelts and windbreaks containing ponderosa pine in the central Plains. In fact, the problem is now so serious in some localities that new plantings of ponderosa pine are being discouraged. This Note reports the successful results of a study designed to determine the effectiveness of two systemic chemicals for control of tip moth on ponderosa pine.

Literature Review

Swenk (1927) studied the western pine tip moth and found the insect has two complete, but overlapping, generations annually in the Nebraska National Forest. The first and second larval generations occur, respectively, in late May to late July, and in early July to late August.

Infestation and damage apparently are most severe on trees 2 to 12 feet tall. Damage is caused by tip moth larvae which bore into and feed on the inner tissues of needle fascicles,

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buds, and shoots. Evidences of infestation are discoloration and browning of needles near branch or leader tips, resin and fecal accumulation at the base of buds, and dead buds and branch tips. Height growth may be slowed as a result of repeated attacks and die-back of the terminals (Boyd et al. 1968).

Control measures in the past included pruning and destroying infested tips containing larvae and pupae, and cutting and burning infested trees. DDT and other organic insecticides were also used (Fenton and Afanasiev 1946).

Systemic insecticides have been widely tested recently for effectiveness in control of the pine tip moth. Since these chemicals are highly toxic to mammals, however, they must be applied with caution. Wasser (1969) and Yates and Lewis (1969) developed equipment and techniques for safe application of certain of these systemic insecticides to trees in seed orchards.

Schuder (1960) applied phorate, phosphamidon, and dimethoate at rates of 1 pound active ingredient per 100 gallons of water to infested pines. Phorate reduced the number of trees infested with the Zimmerman pine tip moth from 18 to 5, and phosphamidon and dimethoate reduced the infestation from 18 to 1 and 0, respectively. Kulman and Dorsey (1962) controlled the European pine shoot moth on red pine with spring applications of granular phorate and disulfoton at rates up to 1.2 ounces active ingredient per tree. They found phorate superior to disulfoton in all tests. Cade and Heikkenen (1965) found phorate and disulfoton granules, at 50 pounds per acre (actual) to be 96 and 100 percent effective in controlling second and third generations of tip moth in loblolly pine seed orchards.

Barras et al. (1967) achieved effective control of tip moth on 2-year-old loblolly pine seedlings for one and one-half growing seasons by using 42 grams of 10 percent granular phorate (4.2 g. actual ingredient) per tree. Yates (1970) obtained effective control of third generation pine tip moths (presumably one season) on 8-foot-tall loblolly pine seed orchard trees with 20 grams of 10 percent granular phorate (2 g. actual) per tree.

Boyd et al. (1968) found either band or broadcast soil treatments of phorate granules applied within the drip-line of the tree crowns to be equally effective. Results were similar whether granules were incorporated into the soil or applied to the surface. Surface applications were more effective when wetted to obtain quicker uptake of the chemicals into the plants. Although both formulations wer effective, the granules were safer, easier t handle, and gave more extended control than drenches, which gave quicker but less lasting control.

Materials and Methods

A study was established in 1964 on a sand loam site in north-central Nebraska, to determine how species composition and tree spacin affects the development of single-row field shelterbelts. The young ponderosa pine in thes shelterbelts had become heavily infested wit the western pine tip moth by 1968. Damag to terminal and lateral shoots was extensive Control measures were necessary to maintai the trees for the original experiment. It wa decided, therefore, to superimpose a short-ter tip moth control study over the original stud in such a manner as to minimize any confounding effects.

Two rows in the study contained ponderos pine. In one of these the pines were plante alternately with eastern redcedar (*Juniperu virginiana* L.) at 6- and 8-foot spacings an alternately in groups of two at 4-foot spacing The other row was exclusively ponderosa pine The pines were 5 years old in the field, an averaged about 3.5 feet tall.

Two systemic insecticides were chosen fo the tests: (1) phorate granules (0,0-diethyl S (ethylthio) methyl phosphorodithioate) know under the trade name of Thimet 15G,[3] an (2) dimethoate spray (0,0-dimethyl S- (N-methyl carbamoylmethyl phosphorodithioate), know under the trade name of Cygon ^{267} . Fou treatments were used:

1. 40 grams phorate (6 grams active) per tree
2. 80 grams phorate (12 grams active) per tree
3. Dimethoate spray at 1 quart per 50 gallons o water (0.166 percent active).
4. Check - no treatment.

Two hundred forty ponderosa pine tree were randomly designated for treatments in th two rows. The 40-gram phorate treatment wa applied to 60 trees in the mixed pine-redceda row (Row II). The 80-gram phorate treatmen was applied to 60 trees in the all ponderos pine row (Row I).

Granular phorate was applied April 22, 1969 It was sprinkled by means of a plastic tub held downwind, over the previously raked soil

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[3] *Trade names are used for the benefit o the reader, and do not imply endorsement o preferential treatment by the U. S. Department of Agriculture.*

t was applied out to the crown drip-line beneath each tree, and then raked in. Dimethoate was applied with a high-pressure sprayer to the point of runoff to 60 trees on May 27 and again on July 1. The aim was to control the insect during both the first and second larval stages as suggested by Swenk (1927).

All other ponderosa pines not selected for reatment evaluation in the two rows were also sprayed with dimethoate. Care was taken o keep the dimethoate spray away from both he untreated checks and the phorate-treated rees.

To minimize the possibility of phorate uptake by trees of the other treatments, the phorate-reated trees were selected so that they were never directly adjacent to trees of other treatments. Thus, the study trees, except for a ew dimethoate-sprayed trees being adjacent to a few check trees, were always separated either by intervening eastern redcedar trees or non-study trees sprayed only with dimethoate. The principal disadvantage of this scheme was reduction of the sensitivity of the check treatment in that random location throughout the study could have lessened the overall probability of attack on check trees.

Infestation on the study trees of record was evaluated four times:

1. July 1969, after completion of the first generation and prior to the second application of the dimethoate spray.
2. December 1969, after completion of the second generation.
3. July 1970.
4. October 1970, two growing seasons and four generations of tip moths after treatment.

Results

Terminal Infestation [4]

Data are discussed separately for each shelterbelt in terms of Rows I and II, since different rates of phorate were applied and species composition was different (fig. 1).

Infestation of the terminal shoots before treatment was 75 and 94 percent, respectively, in Rows I and II. Percentages of infestation among groups of trees to be treated within each row were not significantly different.

Evaluation, July 1969.—Percentage infestation on check trees in July 1969 remained relatively high—60 and 53 percent, respectively, in Rows I and II. The dimethoate-sprayed trees, however, showed only 2 percent terminal infestation in Row I and none in Row II.

The phorate treatments had 48 and 27 percent infested terminals in Rows I and II, respectively. While differences in infestation between the check and the phorate treatment were not significant in Row I, they did attain significance when data from both rows were combined.

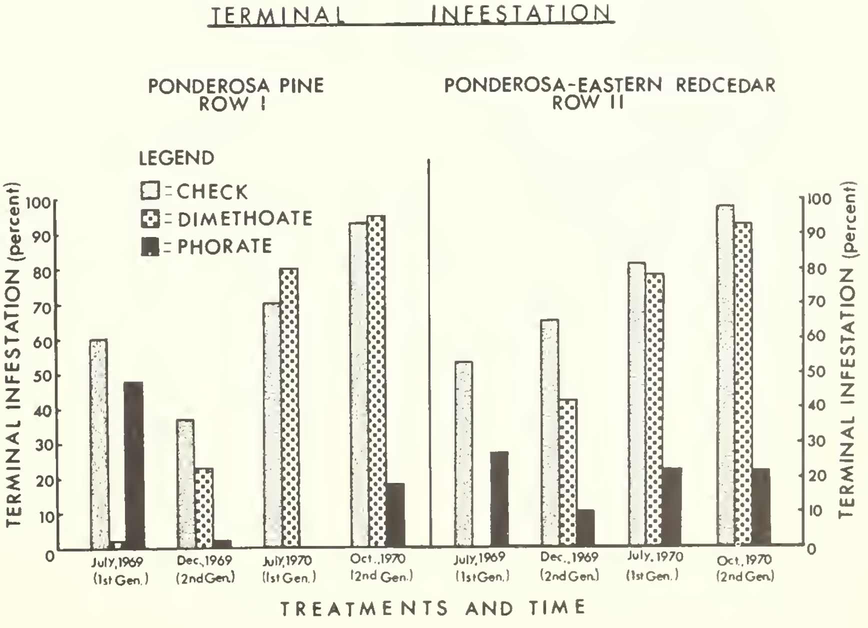

Figure 1.--Percent terminal infestation on ponderosa pine during two growing seasons following treatment with systemic insecticides phorate (Thimet 15G, 12 grams active ingredient per tree, Row 1; and 6 grams active ingredient, Row 11) and dimethoate (Cygon 267, 1 quart per 50 gallons of water, 0.166 percent active ingredient).

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[4] Infestation means either the presence of living larvae in the shoots during the growing season or the presence of damaged tissue caused by larvae having been in the shoots earlier. Terminal refers only to the dominant (tallest) shoot of the trees.

Evaluation, December 1969.—Phorate treatments showed increasing effectiveness in controlling the second-generation infestation of terminal shoots. Percentage of infested terminals had dropped to 2 percent in Row I and 10 percent in Row II. At the same time percentage infestation had increased to 23 and 42 percent, respectively, in Rows I and II on dimethoate-sprayed trees. The check trees still showed a relatively high infestation—37 and 65 percent in Rows I and II. The difference in infestation between dimethoate-treated and check trees in Row I did not quite attain significance, but all treatments were significantly different when data for both Rows I and II were pooled.

Evaluation, July 1970.—Evaluation of treatments after one and one-half growing seasons, three tip moth generations after treatment, revealed no residual effect on the previous year's application of dimethoate. Check and dimethoate-treated trees showed similar infestation percentages of 70 and 80 percent in Row I and 81 and 78 percent in Row II (fig. 1). Phorate-treated trees, on the other hand, showed significantly lower infestation percentages of 0 and 22 percent in Rows I and II, respectively. The 22 percent in Row II suggests the 40-gram rate of phorate was weakening somewhat—but was still satisfactorily effective relative to the other treatments.

Evaluation, October 1970.—Two growing seasons after treatment, the dimethoate-treated trees were as heavily infested as the check trees, 95 and 93 percent and 93 and 97 percent infestation in Rows I and II, respectively (fig. 1). In contrast, the percentage infestation on terminals of all phorate-treated trees was significantly less than either the check or dimethoate-treated trees, but had increased to 18 percent in Row I—the 80-gram-per-tree rate—and remained at 22 percent in Row II.

Lateral Branch Infestation

Infestation on lateral branches was initially evaluated only on the main shoots of the lateral branches. In the two shelterbelts in April 1969 before treatment, 84 and 89 percent of the main lateral branch tips were infested. Differences among the groups of trees within each row prior to treatment were not significant.

Subsequent evaluations of lateral branch infestation in December 1969 and thereafter, however, included all tips on each lateral branch, not just the main shoots. Data are expressed in numbers rather than percentage. While the initial and subsequent data are not directly comparable, the lack of differences among the study trees prior to treatment, the prominent differences among groups of trees after treatment, and the strong correlation of lateral and terminal branch infestation data are obvious.

Evaluation, December 1969.—Numbers of lateral branches infested on check trees averaged about 20 per tree. In contrast, the dimethoate-spray treatment had 10 to 13 infested latera tips per tree, while the phorate treatment showec only 3 to 4 infested lateral tips per tree (fig. 2). Differences among all treatments were significant in combined data for both shelterbelts

Evaluation, July 1970.—Tip moth infestation of lateral branches on check and dimethoate-treated trees was five to seven times greate than on phorate-treated trees (fig. 2). Thi

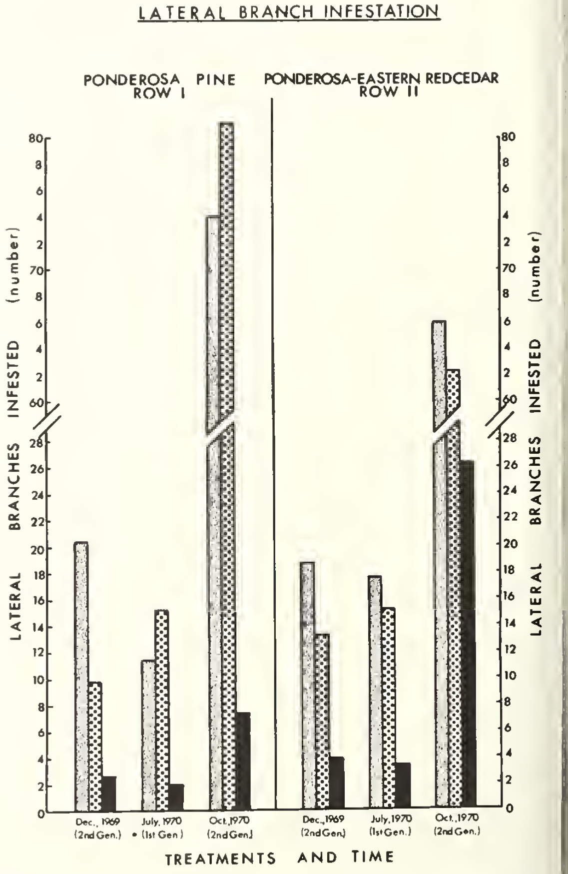


Figure 2.--Number of lateral branch tips infested on ponderosa pine during two growing seasons following treatment with systemic insecticides phorate (Thimet 15G) and dimethoate (Cygon 267).

emonstrated the continued effectiveness of oth phorate treatments and no carryover effect f dimethoate.

Evaluation, October 1970.—A marked in-rease was evident in the incidence of attack n all trees during the second generation. he data clearly showed, however, a residual ffect of the phorate treatment. Infestation cidences of 74 and 66 on check trees, 81 and 2 on dimethoate-treated trees, and 7 and 26 n phorate-treated trees were recorded (fig. 2). lthough the phorate-treated trees showed an crease in incidence of lateral branch infesta-ion, especially at the 40-gram-per-tree rate, hey were still significantly and acceptably less nfested than the check and dimethoate-treated rees.

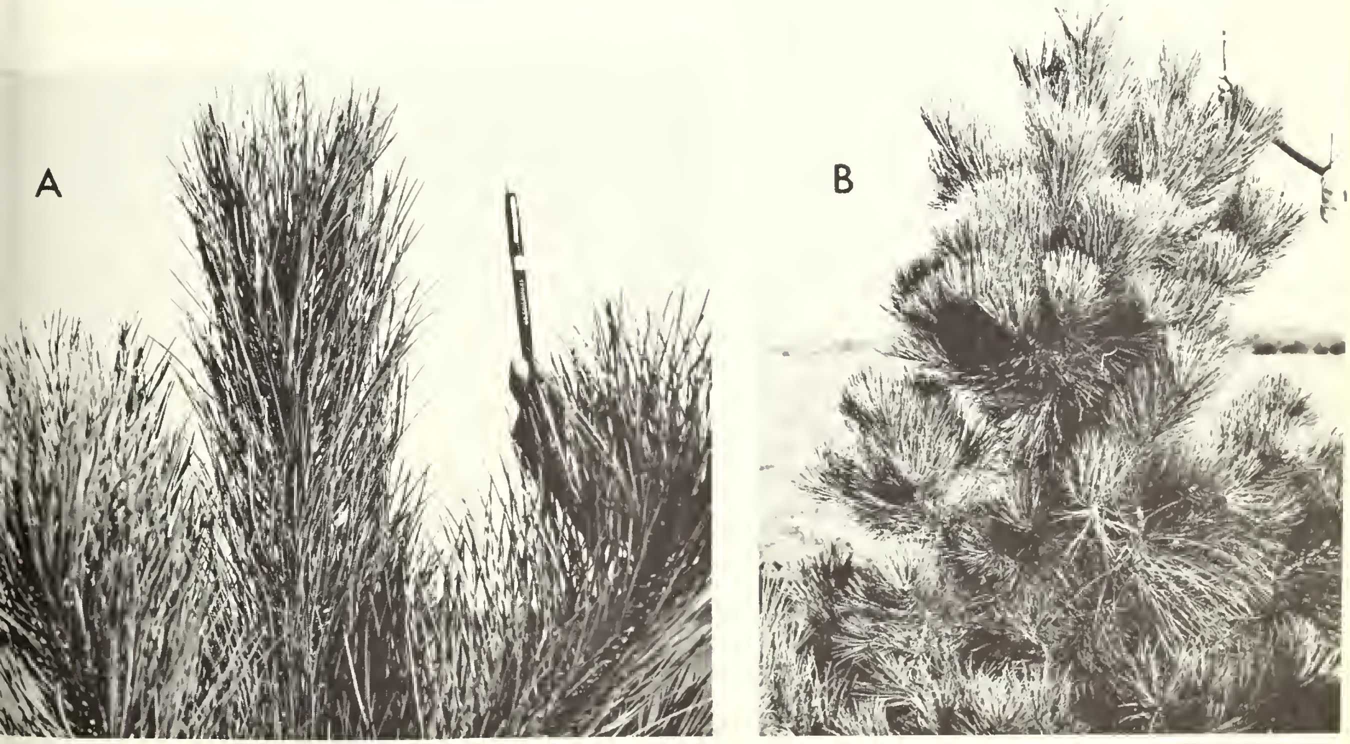
eight Growth

Trees averaged 3.8 and 3.2 feet tall in Rows and II, respectively, before treatment. Differences among groups of trees by treatment within each row were not significant. Measurements to the nearest live part of the terminal in December 1969 revealed that trees in Row I had grown an average of 1.0 foot during the first growing season following treatment, while trees in Row II had grown 0.7 foot. Treatments had no significant effect on height growth in 1969, however.

By October 1970, phorate-treated trees averaged 0.5 foot taller in both shelterbelts than the dimethoate-treated and check trees. While height differences between treatments have not yet achieved significance, it is presumed that they would in another year if the treatments were repeated.

No foliage burn or other visible symptom of phytotoxicity was noticed on any trees during the study. On the contrary, by October 1970, the shiny, dark green foliage and healthy appearance of the phorate-treated trees contrasted markedly with the pale green foliage and dead shoots of dimethoate-treated and untreated check trees (figs. 3, 4).

Figure 3.--Vigorous, healthy terminal and lateral branches (A), and renewed, robust development (B), of phorate-treated ponderosa pine trees two growing seasons after treatment.



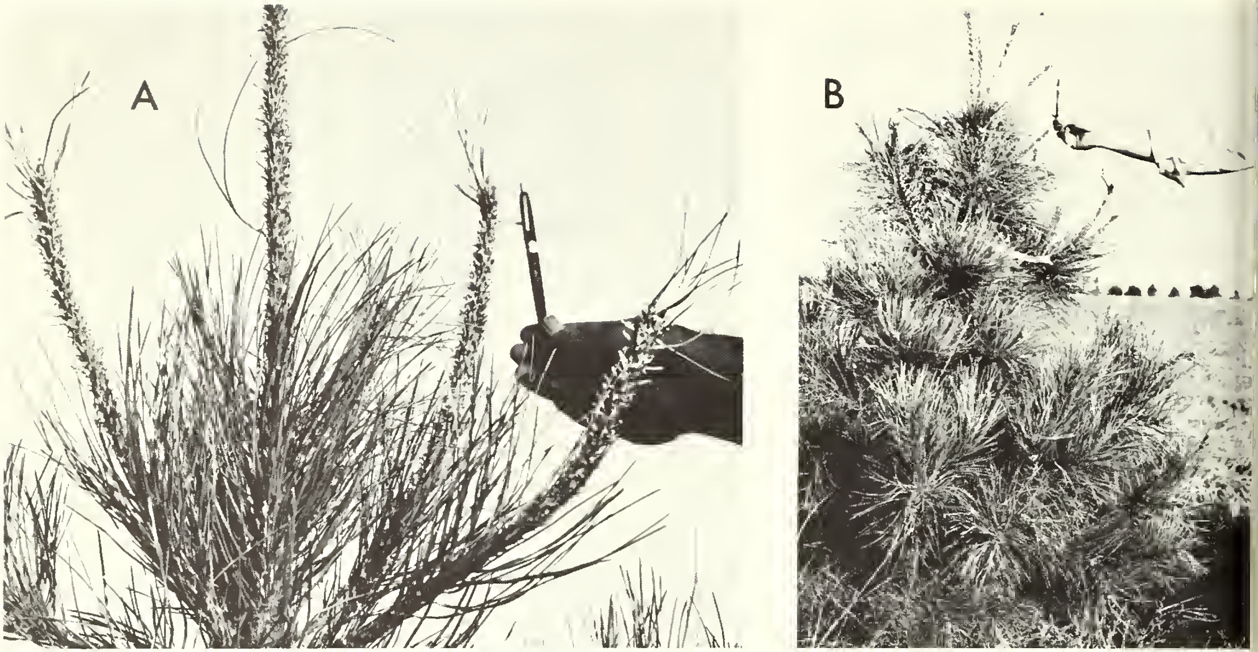


Figure 4.--Dead terminal and lateral branch tips (A), and less vigorous, more chlorotic and multi-branched untreated check and dimethoate-treated trees (B), 2 years following treatment.

Interpretation

The first application of dimethoate spray was apparently effective and well timed, for it gave excellent control of the first generation of tip moth. However, it apparently had little carryover effect on the second generation, a result similarly experienced by Boyd et al. (1968).

The second application of dimethoate apparently was either not as effective as the first application, or its application was not timed with occurrence of the second-generation larval stage of the tip moth. Thus, as in the earlier spray programs which used DDT and other chlorinated hydrocarbons, repeated sprayings and a precise knowledge of life cycle stages for specific localities are necessary to obtain effective control with this chemical.

The April applications of dry, granular phorate apparently were not absorbed into the trees in time to be completely effective during the first generation of the tip moth. Boyd et al. (1968) found that it usually requires 46 to 56 days for granular applications of systemic insecticides to become effective. They recommended October and November as the best time to apply granular phorate in Oklahoma. In view of the possible danger to foraging wildlife during the winter, however, a lat winter or early spring application would seer equally effective. Late winter snows and earl spring rains would carry the insecticide int the soil for translocation through the root and into the trees in time to be effective Applications of granular phorate are not d pendent upon critical timing to life cycle stage of the tip moth, and can be made when othe farm work is relatively light.

Both rates of phorate (Thimet 15G) teste provided very effective control in 1969 an through the first generation of tip moths i July 1970, and acceptable control through th second (1970) growing season. Examinatio of the individual tree data revealed that onl occasional trees in the 40-gram treatment (fig 2, Row II) had become highly vulnerable t attack. Thus, the increase to 26 lateral branc tips infested was due to relatively few trees The majority of phorate-treated trees remaine conspicuously "clean" at the end of the 197 growing season.

Dimethoate (Cygon^{267}) spray also provide effective control of the pine tip moth. Appl cations, however, required precise timing t emergence of larval stages and had less carr over effect than granular phorate.

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NOTICE

This Note describes research on the use of phorate (Thimet) to protect trees. Because registration for this use of phorate was withdrawn after the research was completed, the results presented here cannot be interpreted to be recommendations for its use.

USE PESTICIDES CAREFULLY

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key -- out of the reach of children and animals -- and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: *Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U. S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.*

PROTECT

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Predicting Scaled Volume Recoverable from Cutover Southwestern Ponderosa Pine Stands

Peter F. Ffolliott, Frederic R. Larson, Roland L. Barger[1]

Standard volume tables provide a means of estimating average gross volume per tree in standing timber. The gross volume actually recoverable from the timber may vary from estimated volume because of (1) differences between assumed volume table utilization standards and actual logging practices, (2) differences in form of timber, and (3) differences between stick-scaled and equation-calculated volumes. The tables presented provide a means of predicting scaled volume recoverable from cutover southwestern ponderosa pine stands on sites of low and intermediate quality.

KEY WORDS: *Pinus ponderosa, tree increment estimates, tree volume tables.*

Standard volume tables provide a means of stimating average gross volume per tree in tanding timber. The gross volume actually ecoverable from the timber may vary from stimated volume because of:

. Differences between utilization practices and the utilization standards assumed in constructing the standard volume table;

. Differences between the form of the timber and the average form represented by the standard volume table;

. Differences between stick-scaled board-foot volume and volume calculated by equation (particularly where equation calculations are in Scribner scale and stick-scale is in Scribner Decimal C).

The tables presented in this Note provide a means of predicting scaled volume recoverable from cutover southwestern ponderosa pine (Pinus ponderosa Laws.) stands on sites of low and intermediate quality.

The Sample and the Sampling Area

Sample trees were selected by establishing a series of randomly located 2-chain strips across a 450-acre clearcut sale area; all sawtimber trees within the strips were sample trees. A total of 1,565 sample trees 11 inches diameter breast high (d.b.h.) and larger were measured and scaled on the ground after felling.

Site index[2] on the study area ranged from 44 to 70, and averaged 56. The general form

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[1] *Associate Silviculturists and Principal ood Technologist, respectively, located at lagstaff in cooperation with Northern Arizona niversity; central headquarters maintained at ort Collins, in cooperation with Colorado tate University. Dr. Ffolliott is currently ssistant Professor, Department of Watershed anagement, University of Arizona, Tucson.*

[2] *Meyer, Walter H. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agr. Tech. Bull. 630. 59 p. (Revised.) 1961.*

and character of the timber is reflected in the range of log height-diameter combinations included in the basic data (blocked out in tables 1-6). The area is representative of cutover ponderosa pine on low and intermediate sites, which support a large proportion of the regional timber resource.

Analysis Methods

Measurements of d.b.h., merchantable height, diameters inside bark at stump and at each log height, and board-foot scale were obtained for each sample tree. Gross Scribner Decimal C scale was determined for each 16.5-foot saw log in the tree, and for top half-logs where present, to a variable minimum merchantable diameter. Most blackjack ponderosa pine trees can be utilized to the minimum saw log merchantability limit specified, usually 8 inches. Minimum merchantable diameter in old-growth timber, however, is more often governed by top branching characteristics than by diameter.

Gross cubic-foot volume was determined for each log and half-log in sample trees by applying the formula for volume of a frustum of a cone to individual half-log stem sections.

Tables of predicted gross board-foot and cubic-foot volume recovery were developed by means of the combined variable regression model: [3]

$V = a + b D^2 H$

where

V = gross recoverable volume

D = d.b.h., outside bark, in inches

H = merchantable height, in logs

a and b = constants

Tree Height Conversion

All tables of recoverable volume are based on merchantable tree height in 16-foot logs and half-logs. Where total tree height measurements are available instead, they can be converted to log heights with the following tabulation or equation, covering both old-growth and blackjack trees:

Total tree height (Feet)	Estimated height in 16-foot logs (Number)
31	0.5
38	1.0
45	1.5
53	2.0
60	2.5
67	3.0
74	3.5
82	4.0

Height in 16-foot logs can be estimated directly for both blackjack and old-growth trees by the equation:[4]

$Y = 0.069X - 1.63$

where

Y = number of 16-foot logs

X = total tree height, in feet

The Tables

Tables of recoverable volume are presented for both board-foot and cubic-foot volumes in blackjack and old-growth ponderosa pine. Some users prefer volume data based on full inch classes (for example 20.0-20.9), while others prefer diameter classes that break on the half inch (e.g., 19.6-20.5). Tables are provided for both systems.

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[3] *Husch, Bertram. Forest mensuration and statistics. 474 p. New York: The Ronald Press. 1963.*

[4] *Regression based on subsample of 74 trees.*

Table 1.--Gross scaled volumes in board feet Scribner rule, cutover blackjack ponderosa pine

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs							Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	
Midpoint at full inch:[1]	- - - - - - - - - - -	- - - - - - - - - - -	- - - - - - - - - - -	Volume in board feet	- - - - - - - - - - -	- - - - - - - - - - -	- - - - - - - - - - -	Number
11.0	14	26	38	51	63	75	88	193
12.0	16	31	45	60	75	89	104	182
13.0	19	36	53	70	87	105	122	104
14.0	21	41	61	81	101	121	141	63
15.0	24	47	70	93	116	139	162	35
16.0	28	54	80	106	132	158	184	19
17.0	31	60	90	119	148	178	207	15
18.0	34	67	100	133	166	199	232	10
19.0		75	112	148	185	222	258	3
20.0		83	123	164	205	245		1
21.0		91	136	181	226			1
22.0			149					0
Midpoint at half-inch:[2]								
11.5	15	28	42	55	69	82		86
12.5	17	33	49	65	81	97	113	206
13.5	20	39	57	76	94	113	131	138
14.5	23	44	66	87	108	130	151	88
15.5	26	50	75	99	124	148	172	45
16.5	29	57	85	112	140	168	195	25
17.5	33	64	95	126	157	188	219	20
18.5	36	71	106	141	175	210	245	8
19.5	40	79	117	156	195	233	272	8
20.5		87	130	172	215	258		0
21.5		95	142	189	236	283		2
22.5			156		259			0
Basis: No. trees	3	100	254	197	61	10	1	626

Block indicates extent of basic data.
Derived from $V = 1.5469 + 0.2032\ D^2H$.
Standard error of estimate = $\pm$21.81 percent.

[1] Diameter class breaks at half-inch: e.g., 20-inch class includes 19.6 to 20.5.
[2] Diameter class breaks at full inch: e.g., 20-inch class includes 20.0 to 20.9.

Table 2.--Gross scaled volumes in board feet Scribner rule, cutover old-growth ponderosa pine

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs										Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
Midpoint at full inch:[1]	Volume in board feet										Number
11.0	15	29	43	57	72						10
12.0	18	35	51	68	85	102					19
13.0	21	40	60	80	100	119	139				34
14.0	24	47	70	93	115	138	161				38
15.0	27	54	80	106	132	159	185	211			49
16.0	31	61	91	121	151	180	210	240			80
17.0	35	68	102	136	170	204	237	271	305		102
18.0	39	77	115	152	190	228	266	304	342		101
19.0	43	85	127	170	212	254	296	339	381		105
20.0	48	94	141	188	235	281	328	375	422		71
21.0	52	104	156	207	259	310	362	413	465		88
22.0	57	114	171	227	284	340	397	454	510		59
23.0	63	125	186	248	310	372	434	496	557		52
24.0	68	136	203	270	338	405	472	540	607	674	45
25.0		147	220	293	366	439	512	585	658	732	25
26.0		159	238	317	396	475	554	633	712	791	27
27.0		171	257	342	427	512	597	683	768	853	13
28.0			276	367	459	551	642	735	826	917	2
29.0			296	394	492	591	689	787	886	984	2
30.0			317	422	527	632	737	843	948	1053	6
31.0				450	563	675	787	900	1012	1124	2
32.0				480	599	719	839	959	1078	1198	3
33.0				510	637	765	892	1019	1147	1274	2
34.0				541	677	812	947	1082	1217		0
35.0				574	717	860	1003	1147	1290		1
36.0				607	758	910	1061	1213	1364		1
37.0					801		1121	1281	1441		2
38.0								1351			0
Basis: No. trees	8	57	145	270	213	150	57	35	3	1	939

Block indicates extent of basic data.
Derived from V = 0.8969 + 0.2338 D^2H.
Standard error of estimate = $\pm$27.19 percent.

[1] Diameter class breaks at half-inch: e.g., 20-inch class includes 19.6 to 20.5.

Table 3.--Gross scaled volumes in board feet Scribner rule, cutover old-growth ponderosa pine

Board feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs										Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
Midpoint at half-inch:[1]	Volume in board feet										Number
11.5	16	31	47	63							3
12.5	19	37	56	74	92	110					20
13.5	22	44	65	86	107	129	150				15
14.5	25	50	75	99	124	148	173				49
15.5	29	57	85	113	141	169	197				35
16.5	33	65	96	128	160	192	224	256			70
17.5	37	72	108	144	180	216	252	287			94
18.5	41	81	121	161	201	241	281	321	361		94
19.5	43	90	134	179	223	268	312	357	401		94
20.5	50	99	148	197	247	296	345	394	443		102
21.5	55	109	163	217	271	325	379	433	487		68
22.5	60	119	178	238	297	356	415	474	534		89
23.5	65	130	195	259	324	388	453	517	582		52
24.5	71	141	211	282	352	422	492	562	632		44
25.5	77	153	229	305	381	457	533	609	685	761	32
26.5		165	247	329	411	493	576	658	740	822	31
27.5		178	266	355	443	531	620	708	797	885	22
28.5		191	286	381	476	571	666	761	855	950	6
29.5			306	408	510	611	713	815	916	1018	2
30.5			327	436	545	653	762	871	980	1088	4
31.5				465	581	697	813	929	1045	1161	4
32.5				495	618	742	865	989	1112	1236	1
33.5				526	657	788	919	1050	1182	1313	2
34.5				557	697	836	975	1114	1253	1392	2
35.5				590	738	885	1032	1179	1327		0
36.5				624	780	935	1091	1247	1403		1
37.5				658	823	987	1152	1316	1480		2
38.5					867		1214	1387	1560		1
Basis: No. trees	8	57	145	270	213	150	57	35	3	1	939

Block indicates extent of basic data.
Derived from $V = 0.8969 + 0.2338\ D^2H$.
Standard error of estimate = $\pm$27.19 percent.

[1] Diameter class breaks at full inch: e.g., 20-inch class includes 20.0 to 20.9.

Table 4.--Gross scaled volumes in cubic feet, cutover blackjack ponderosa pine

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs 0.5	1.0	1.5	2.0	2.5	3.0	3.5	Basis: Trees
	Volume in cubic feet							Number
Midpoint at full inch:[1]								
11.0	5	8	10	13	15	18	20	193
12.0	6	9	12	15	18	20	23	182
13.0	6	10	13	17	20	23	27	104
14.0	7	11	15	19	23	27	31	63
15.0	8	12	17	21	26	30	35	35
16.0	8	13	18	24	29	34	39	19
17.0	9	15	20	26	32	38	44	15
18.0	10	16	23	29	36	42	49	10
19.0		18	25	32	39	47	54	3
20.0		19	27	35	43	51		1
21.0		21	30	39	47			1
22.0			32					0
Midpoint at half-inch:[2]								
11.5	6	8	11	14	16	19		86
12.5	6	9	12	16	19	22	25	206
13.5	7	10	14	18	21	25	29	138
14.5	8	12	16	20	24	28	33	88
15.5	8	13	18	22	27	32	37	45
16.5	9	14	19	25	30	36	41	25
17.5	9	15	22	28	34	40	46	20
18.5	10	17	24	31	37	44	51	8
19.5	11	18	26	34	41	49	57	8
20.5		20	28	37	45	54		0
21.5		22	31	40	50	59		2
22.5			34		54			0
Basis: No. trees	3	100	254	197	61	10	1	626

Block indicates extent of basic data.
Derived from $V = 3.0618 + 0.0402\ D^2H$.
Standard error of estimate = ±30.30 percent.

[1] Diameter class breaks at half-inch: e.g., 20-inch class includes 19.6 to 20.5.

[2] Diameter class breaks at full inch: e.g., 20-inch class includes 20.0 to 20.9.

Table 5.--Gross scaled volumes in cubic feet, cutover old-growth ponderosa pine

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs										Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
Midpoint at full inch:[1]	- - - - - - - - - - - - -				Volume in cubic feet		- - - - - - - - - - - - -				Number
11.0	10	12	14	17	19						10
12.0	10	13	16	18	21	24					19
13.0	11	14	17	20	24	27					34
14.0	11	15	19	22	26	30	34				38
15.0	12	16	20	25	29	33	38	42			49
16.0	12	17	22	27	32	37	42	47			80
17.0	13	18	24	30	35	41	46	52	58		102
18.0	14	20	26	32	39	45	51	57	64		101
19.0	14	21	28	35	42	49	56	63	70		105
20.0	15	23	31	38	46	54	61	69	77		71
21.0	16	24	33	41	50	59	67	76	84		88
22.0	17	26	35	45	54	63	73	82	92		59
23.0	18	28	38	48	58	69	79	89	99		52
24.0	18	30	41	52	63	74	85	96	108	119	45
25.0		31	44	56	68	80	92	104	116	128	25
26.0		33	47	60	73	86	99	112	125	138	27
27.0		36	50	64	78	92	106	120	134	148	13
28.0			53	68	83	98	114	129	144	159	2
29.0			56	72	89	105	121	137	154	170	2
30.0			60	77	94	112	129	147	164	181	6
31.0				82	100	119	137	156	175	193	2
32.0				87	106	126	146	166	186	205	3
33.0				92	113	134	155	176	197	218	2
34.0				97	119	142	164	186	209		0
35.0				102	126	150	173	197	221		1
36.0				108	133	158	183	208	233		1
37.0					140	166	193	219	246		2
38.0								231			0
Basis: No. trees	8	57	145	270	213	150	57	35	3	1	939

Block indicates extent of basic data.
Derived from V = 7.3073 + 0.0387 D^2H.
Standard error of estimate = $\pm$18.69 percent.

[1] Diameter class breaks at half-inch: e.g., 20-inch class includes 19.6 to 20.5.

Table 6.--Gross scaled volumes in cubic feet, cutover old-growth ponderosa pine

Cubic feet inside bark
Merchantable stem excluding stump and top

Top diameter variable
Stump height 1.0 foot

DBH class (Inches)	Number of merchantable 16-foot logs										Basis: Trees
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	
Midpoint at half-inch:[1]	Volume in cubic feet										Number
11.5	10	12	15	18							3
12.5	10	13	16	19	22	25					20
13.5	11	14	18	21	25	28	32				15
14.5	11	15	20	24	28	32	36				49
15.5	12	17	21	26	31	35	40				35
16.5	13	18	23	28	34	39	44	49			70
17.5	13	19	25	31	37	43	49	55			94
18.5	14	21	27	34	40	47	54	60	67		94
19.5	15	22	29	37	44	51	59	65	74		94
20.5	15	24	32	40	48	56	64	72	80		102
21.5	16	25	34	43	52	61	70	79	88		68
22.5	17	27	37	46	56	66	76	86	95		89
23.5	18	29	39	50	61	71	82	93	103		52
24.5	19	31	42	54	65	77	89	100	112		44
25.5	20	32	45	58	70	83	95	108	121	133	32
26.5		34	48	62	75	89	102	116	130	143	31
27.5		37	51	66	80	95	110	124	139	154	22
28.5		39	54	70	86	102	117	133	149	164	6
29.5			58	75	92	108	125	142	159	176	2
30.5			61	79	97	115	133	151	169	187	4
31.5				84	103	123	142	161	180	199	4
32.5				89	109	130	150	171	191	212	1
33.5				94	116	138	159	181	203	224	2
34.5				99	122	145	169	192	215	238	2
35.5				105	129	154	178	202	227		0
36.5				110	136	162	188	214	239		1
37.5				116	143	171	198	225	252		2
38.5					151		208	237	265		1
Basis: No. trees	8	57	145	270	213	150	57	35	3	1	939

Block indicates extent of basic data.
Derived from V = 7.3073 + 0.0387 D^2H.
Standard error of estimate = ±18.69 percent.

[1] Diameter class breaks at full inch: e.g., 20-inch class includes 20.0 to 20.9.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-196

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Processing Size, Frequency, and Speed Data from Snow Particle Counters

R. A. Schmidt[1]

Describes techniques for electronically processing magnetic tape records from a photoelectric snow particle counter. Examples of the resulting particle size distributions, particle frequency plots, and measurements of particle speed are included.

KEY WORDS: Snow (particle size), instrumentation, snow samplers, electronic data processing.

This Note is one of a series on using a photoelectric device to record size and speed of snow particles during blizzards. The objective is to measure snow transport in alpine areas, and thus develop techniques for predicting and controlling snow deposition there. Automatic data processing techniques which translate the magnetic tape records into particle size and speed distributions are described here.

A signal is produced by each particle passing through a photoelectric snow particle counter, as described by Schmidt and Sommerfeld.[2] Two photo transistors are illuminated by a collimated light beam, through two small vertical slits. As the particle blocks the light to the first slit, the signal goes positive, and when it passes between the light source and the second slit the signal becomes negative (fig. 1). There is an overshoot after each pulse which results from the characteristics of the amplifier and photo transistors, and the signal also contains diode noise.

Measurements in the field are recorded in analog form on magnetic tape with frequency-modulated (FM) recording equipment. Recordings are made at a tape speed of 60 inches per second (ips); the frequency response of the recorder (bandwidth 0 to 10KHz) is adequate for the particle counter signals.

Magnetic tapes are analyzed in the laboratory. The noise on the signal, monitored by a storage-type oscilloscope (fig. 2), is the total due to sensor, recorder, and reproducer; it is a problem which must be overcome in determining particle size distributions from the data.

Particle Size Distributions

Calibration of the snow particle counter with sieved snow particles[3] indicated a linear relation between peak signal amplitude (A in fig. 1) and particle "sieve diameter." With this relation, the distribution of sizes of particles is determined by counting signals with successively larger amplitudes in successive replays of the tape. The number of particles in some 10 to 15 size classes can be determined by subtracting the various counts. This amplitude discrimination could be more rapidly obtained with multichannel instruments such as those used to analyze nuclear pulses, but such equipment was not available.

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[1] *Hydrologist, Rocky Mt. Forest and Range Exp. Sta., with central headquarters maintained at Fort Collins in cooperation with Colorado State University.*

[2] *Schmidt, R. A., and R. A. Sommerfeld. A photoelectric snow particle counter. West. Snow Conf. Proc. 37: 88-91. 1969.*

[3] *Schmidt, R. A. Calibrating the snow particle counter for particle size and speed. USDA Forest Serv. Res. Note RM-189, 8 p. Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo. 1971.*

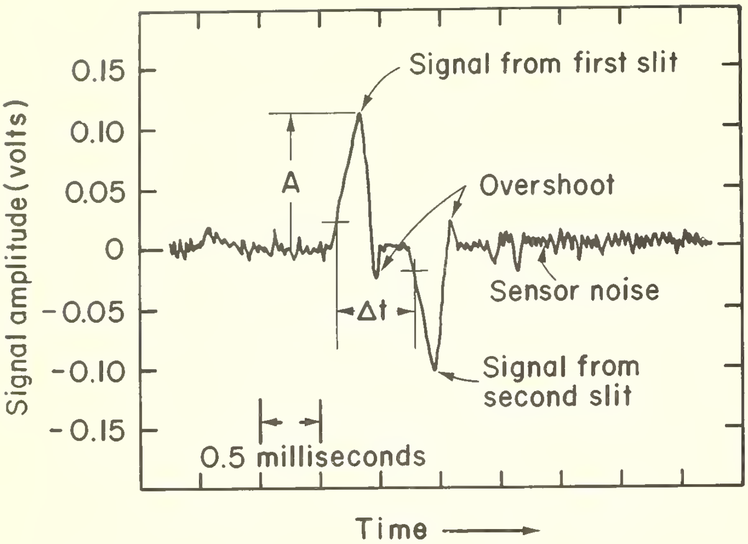
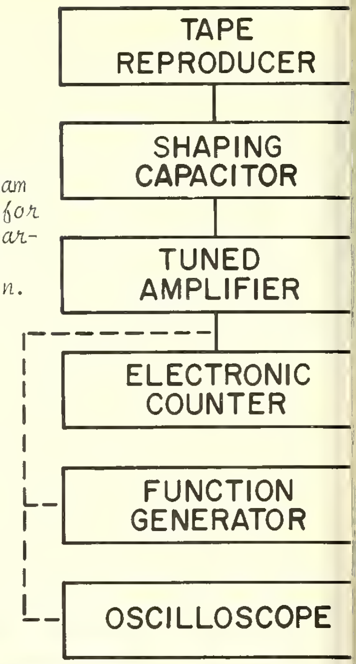


Figure 1.--Diagram of particle signal.

Figure 3.--Block diagram of process for obtaining particle size distribution.



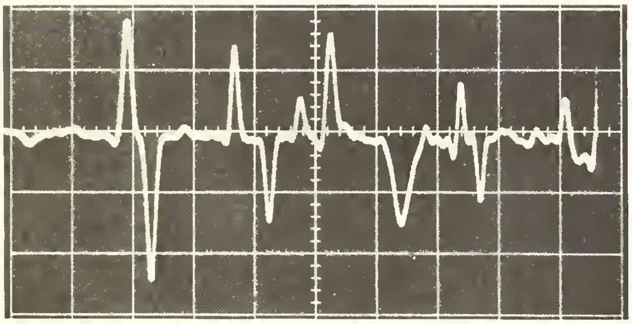


Figure 2.--Oscilloscope photo of particle signals from tape. (Horizontal scale 0.5 milliseconds/div.; vertical, 50 millivolts/div.)

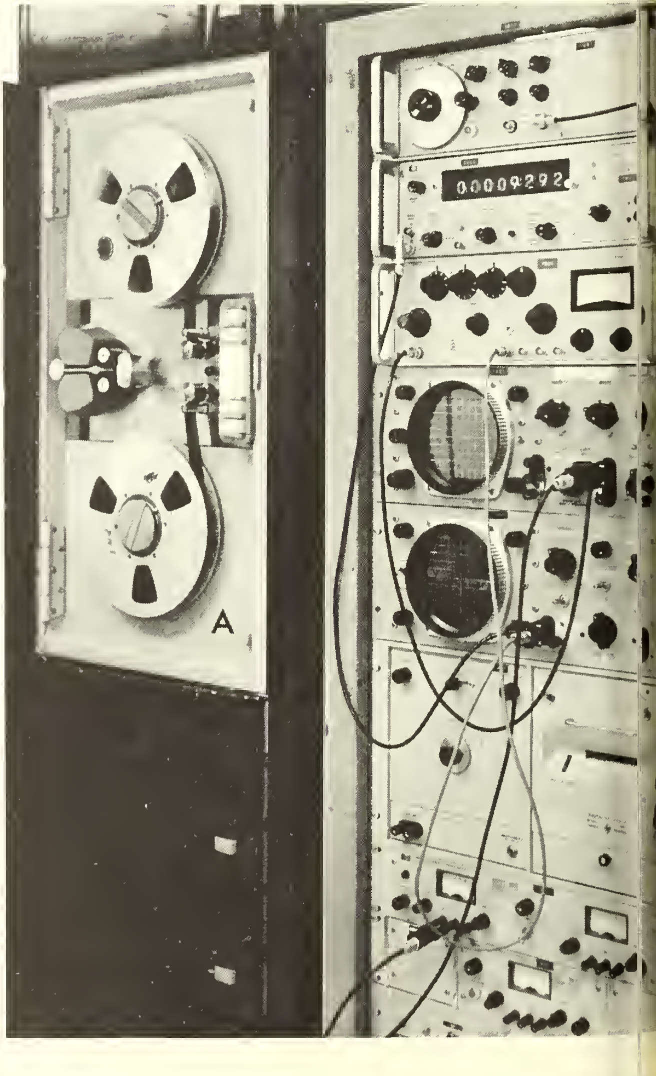


Figure 4.--Photo of equipment:
(A) tape recorder,
(B) function generator,
(C) counter,
(D) tuned amplifier,
(E) scopes,
(F) printer.

Figures 3 and 4 describe the electronic equipment for processing particle counter data to obtain size distributions. The signal from the tape reproducer is first shaped by an RC integrator to reduce the overshoot, diode noise, and tape system noise, all of which are of higher frequency than the desired signal. The signal is filtered to reduce low-frequency (60 cycle) noise and then amplified, so that signals may be counted electronically. Amplifier gain and counter trigger level are set by applying a 5KHz triangular wave form in place of the reproducer output. The signal to the counter is monitored with an oscilloscope, and the output of the function generator is adjusted so the signal has a peak amplitude just equal to the desired minimum trigger level. The counter is then adjusted to begin counting the 5KHz signal at that amplitude. A plot of the resulting particle size distribution (fig. 5) reveals a much larger number of very small particles than previous microscopy methods.

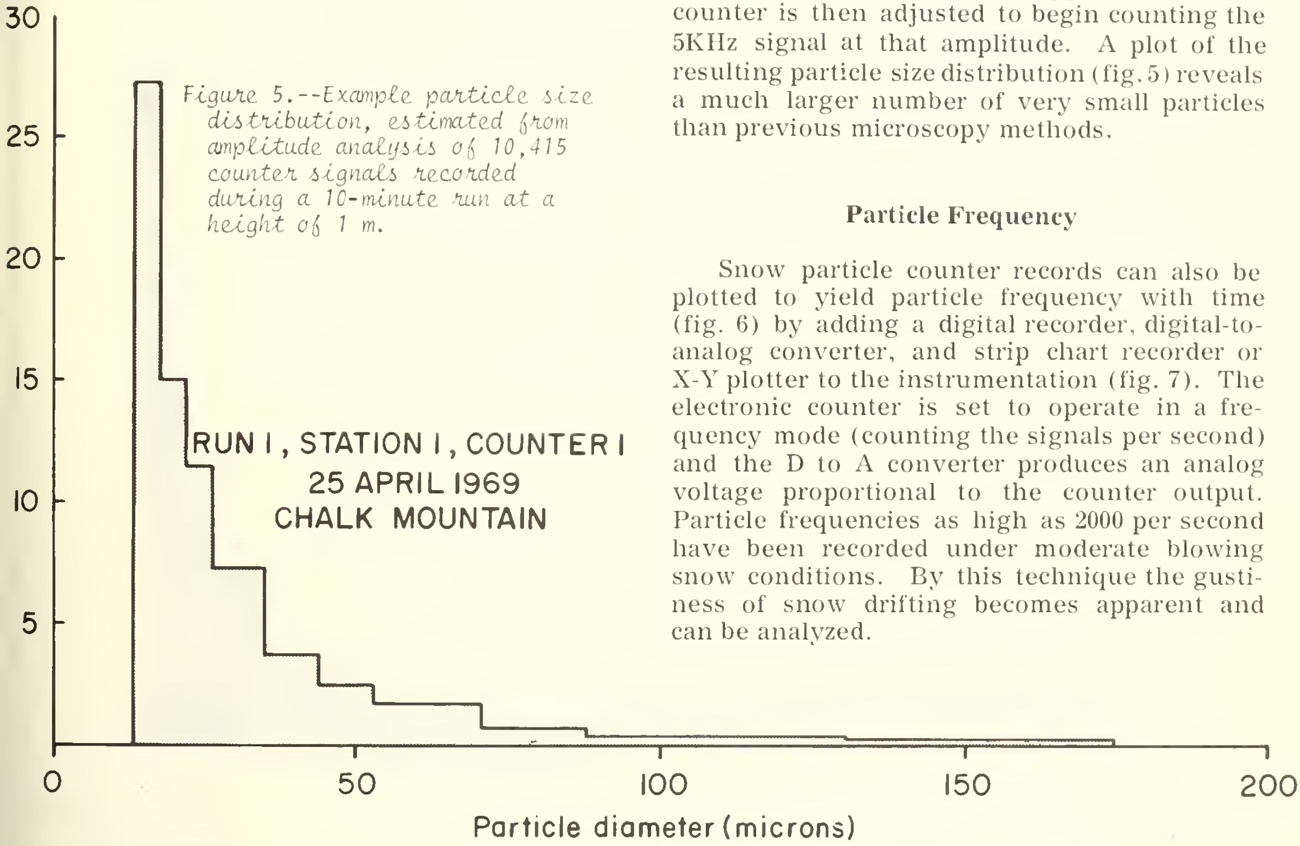


Figure 5.--Example particle size distribution, estimated from amplitude analysis of 10,415 counter signals recorded during a 10-minute run at a height of 1 m.

Particle Frequency

Snow particle counter records can also be plotted to yield particle frequency with time (fig. 6) by adding a digital recorder, digital-to-analog converter, and strip chart recorder or X-Y plotter to the instrumentation (fig. 7). The electronic counter is set to operate in a frequency mode (counting the signals per second) and the D to A converter produces an analog voltage proportional to the counter output. Particle frequencies as high as 2000 per second have been recorded under moderate blowing snow conditions. By this technique the gustiness of snow drifting becomes apparent and can be analyzed.

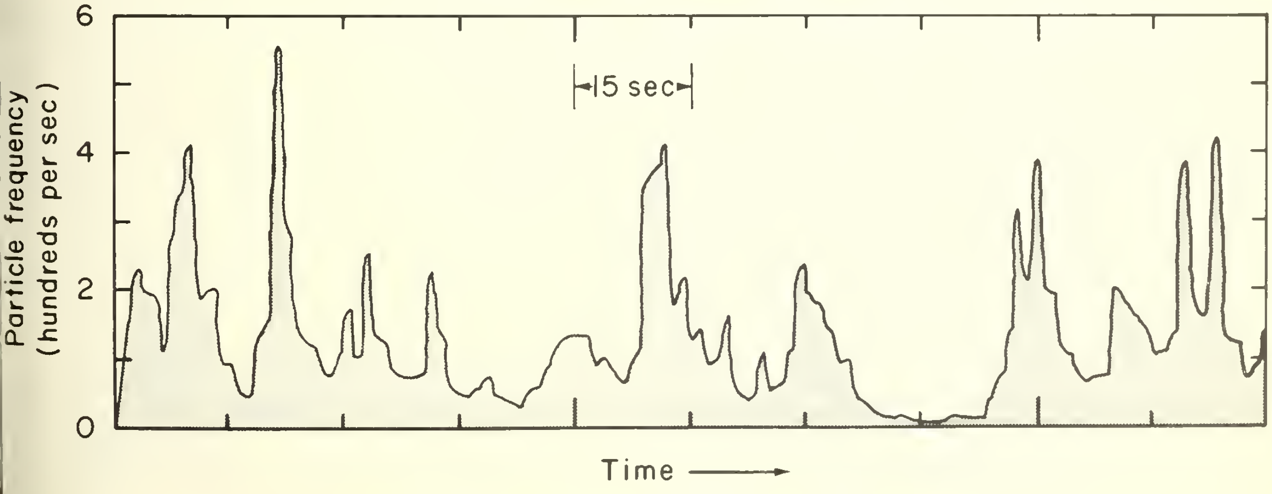


Figure 6.--Example snow particle frequency plot.

Snow Particle Speed

The particle counter was originally designed with two slits to facilitate particle speed measurements.[4] Calibration of modified counters at the Rocky Mountain Station provided a linear relation between particle speed and inverse of time interval Δt (see fig. 1). With an electronic time interval counter, the setup in figure 8 automatically records Δt on the printer. The printout is edited to delete spurious counts, and cards are then punched to enter the data in a digital computer for conversion to particle speed and tabulation of the speed frequency distribution (fig. 9). This type of measurement will help explain the relative motion between snow particles and air, which is fundamental to the evaporation of snow particles during wind transport.

Conclusion

With the techniques described here, the photoelectric snow particle counter provides hitherto unavailable measurements of particle size, frequency, and speed which should greatly increase knowledge of the process of snow transport by wind.

[4] Hollung, O., W. E. Rogers, and J. A. Businger. Development of a system to measure the density of drifting snow. Joint Tech. Rep., Dep. Elec. Eng., Dep. Atmos. Sci., Univ. Wash., Seattle. 54 p. 1966.

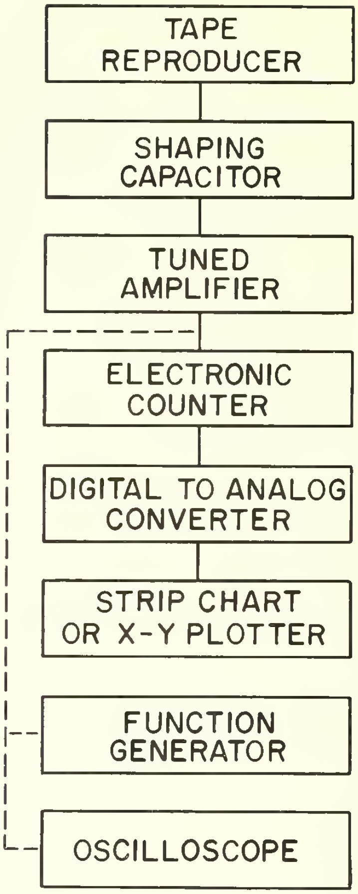


Figure 7.--Block diagram of equipment used to obtain particle frequency.

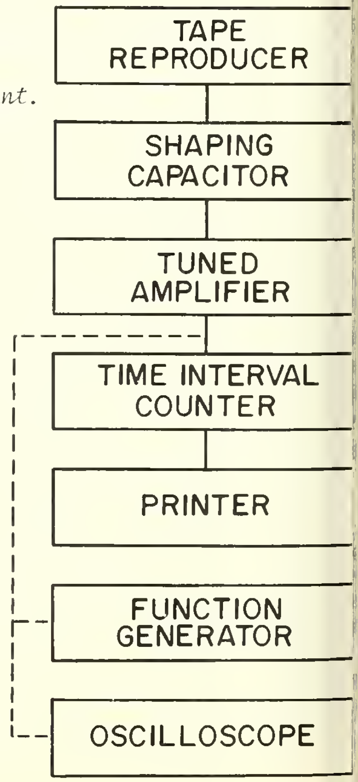


Figure 8.--Block diagram of particle speed analysis equipment.

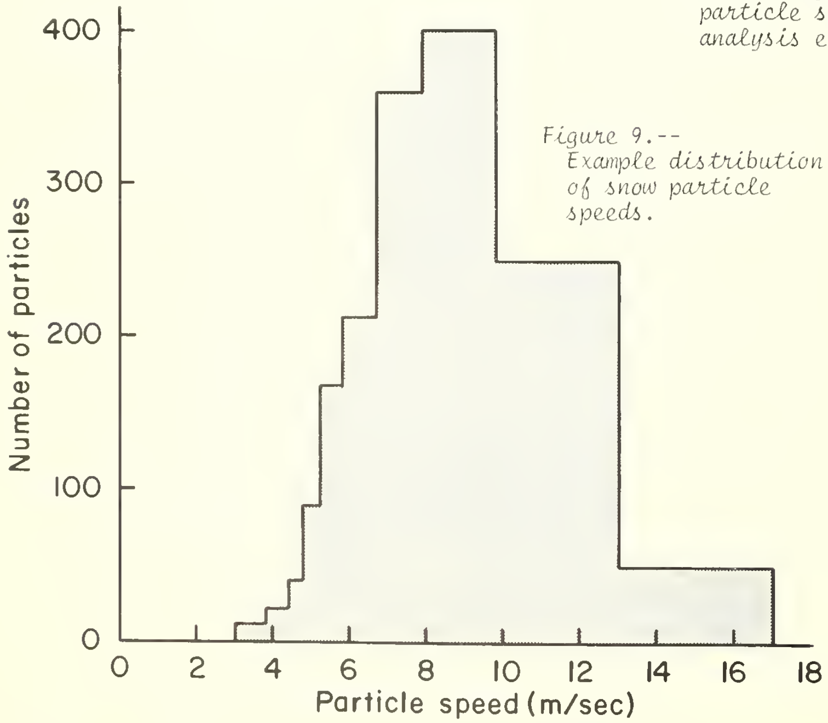


Figure 9.--Example distribution of snow particle speeds.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-197

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Geologic Soil Groupings for the Pinyon-Juniper Type on National Forests in New Mexico

Earl F. Aldon[1] and H. Gassaway Brown III[2]

Almost 29 percent of the pinyon-juniper type is on highly unstable geologic formations that contribute to high sediment yields. Sedimentary units make up 54 percent of the acreage in the type, igneous units 39 percent, and Pre-Cambrian formations 7 percent.

KEY WORDS: Geology, watershed management, pinyon-juniper type.

The pinyon-juniper woodland type covers oout 17.2 million acres, or about 22 percent, New Mexico (Dortignac 1960) (fig. 1). Of is total, over 2.8 million acres are within e seven National Forests in the State able 1). Most of the woodland type occurs elevations of from 4,000 to 7,500 feet, and ten occupies ridges, knolls, breaks, dissected esa edges, escarpments, and rocky outcrops astetter 1956)—sites that frequently contribute gh sediment yields. Precipitation over the pe ranges from 12 to 20 inches annually, and erages close to 14 inches.

As part of our research program on watered rehabilitation, we need to know the broad il groups in the pinyon-juniper type. With is information, we can concentrate our soil abilization research on those sites and soil pes where the results will have the widest plicability, and will be most effective in ducing serious soil erosion problems. This ventory was made to list these groups.

Table 1.--Pinyon-juniper woodland type on National Forests in New Mexico

National Forest	Size[1]	Pinyon-juniper woodland type	
	--Acres--	-Acres-	-Percent-
Apache[2]	616,328	150,270	24.4
Carson	1,440,919	394,616	27.4
Cibola	1,594,086	732,550	46.0
Coronado[2]	69,567	6,744	9.7
Gila	2,702,643	931,164	34.4
Lincoln	1,103,220	269,050	24.4
Santa Fe	1,468,999	358,926	24.4
Total	8,995,762	2,843,320	32.0

[1] U.S. Department of Agriculture, Forest Service (1970).
[2] Large portion lies in Arizona.

We used two kinds of maps in our inventory of soil groups. Geologic information was obtained from Dane and Backman's (1965) Geologic Map of New Mexico, while vegetation type maps were those published by the U. S. Forest Service (1962). Geologic and vegetation maps were overlaid, scales were adjusted with a Saltzman overhead projector, and acreage of woodland and geologic groups was measured by dot grid.

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[1] *Principal Hydrologist, located at Albuerque in cooperation with the University of v Mexico; central headquarters maintained at rt Collins in cooperation with Colorado ate University.*

[2] *Geologist, Division of Watershed Managent, Region 3, USDA Forest Service, Albuquer-e.*

Table 2.--Geologic units in the piny

Geologic unit	Description	Apache NF		C
		Acres	Pct.	Ac
SEDIMENTARY:				
Alluvium--				
Recent	Unconsolidated surficial deposits, primarily in flood plains.	16,640	11.07	21
Older	Poorly consolidated surficial deposits, (bolson, pediment, terrace deposits, etc.); includes Gila conglomerate, Carson conglomerate, and Santa Fe group. Locally, some volcanics may occur.	14,720	9.79	140
Sandstone	Includes Baca formation, Cub Mountain formation, Mesa Verde group, Dakota sandstone, Glorieta sandstone, Yeso formation, and Sangre de Cristo formation.	--	--	28
Limestone	San Andres limestone, Madera limestone, and Artesia group.	--	--	--
Shale--				
Mancos shale[1]	A light- to dark-gray marine shale with interbedded fine-grained sandstone and siltstone.	--	--	25
Morrison formation	A gray, green, tan, and red variegated clay and shale with interbedded gray to red sandstone.	--	--	9
Volcanic detritus and pyroclastics[1]	Includes sedimentary facies that occur within the Datil volcanic complex.	21,120	14.05	--
Red beds[1]	The Triassic Chinle formation and the Permian Abo formation, which are composed of red to brown interbedded shales and sandstones.	--	--	11
Undifferentiated	Includes the combined Sandia (sandstone) formation and Madera limestone; a sequence of Pennsylvania, Mississippian, and Devonian sandstones, shales, and limestones; and an interbedded sequence of evaporites, shales, and sandstones which comprise the San Rafael group. Because San Jose and Nacimiento formations consist of interbedded shales and sandstones, they are included here.	--	--	94
IGNEOUS:				
Datil formation[1]	A thick sequence of extrusive volcanic rocks found in west-central New Mexico; rock types include rhyolite, latite, andesite, and basalt, and occur as tuffs, flows, and breccias.	66,430	44.20	--
Volcanics	All extrusive igneous rocks except those of the Datil volcanic complex; rock types include rhyolite, andesite, and basalt, and generally occur as flows and tuffs.	31,360	20.86	26
Intrusives	Areas of tertiary intrusive rocks, scattered throughout New Mexico, that occur as stocks, laccoliths, dikes, and sills.	--	--	--
MIXED UNITS:				
Pre-Cambrian	Includes igneous and metamorphic rock types; igneous is primarily granite; metamorphic are phyllites, schists, gneisses, and quartzites.	--	--	37
TOTAL		150,270		394,

[1] Delineated separately because they are highly unstable geologic formations and heavy sedimen

on the National Forests in New Mexico

NF	Coronado NF		Gila NF		Lincoln NF		Santa Fe NF		Total	
Pct.	Acres	Pct.	Acres	Pct.	Acres	Pct.	Acres	Pct.	Acres	Pct.
--	--	--	21,120	2.26	--	--	2,180	0.60	61,060	2.14
10.79	--	--	208,954	22.44	1,920	0.71	79,104	22.03	524,125	18.43
26.18	--	--	3,840	.41	59,520	22.12	35,200	9.80	319,185	11.22
3.04	--	--	1,920	.20	142,970	53.13	8,960	2.49	176,130	6.19
1.84	--	--	--	--	10,240	3.80	--	--	49,360	1.73
.17	--	--	--	--	--	--	18,560	5.17	29,440	1.03
--	--	--	17,440	1.87	--	--	--	--	38,560	1.35
3.43	--	--	--	--	8,960	3.33	25,152	7.00	70,792	2.48
7.86	--	--	19,400	2.08	--	--	83,200	23.18	254,484	8.95
26.90	--	--	389,050	41.78	--	--	--	--	652,560	22.95
13.02	6,744	100.00	151,040	16.22	--	--	79,690	22.20	390,504	13.73
1.22	--	--	18,560	1.99	45,440	16.88	--	--	72,960	2.56
5.50	--	--	99,840	10.72	--	--	26,880	7.48	204,160	7.18
	6,744		931,164		269,050		358,926		2,843,320	

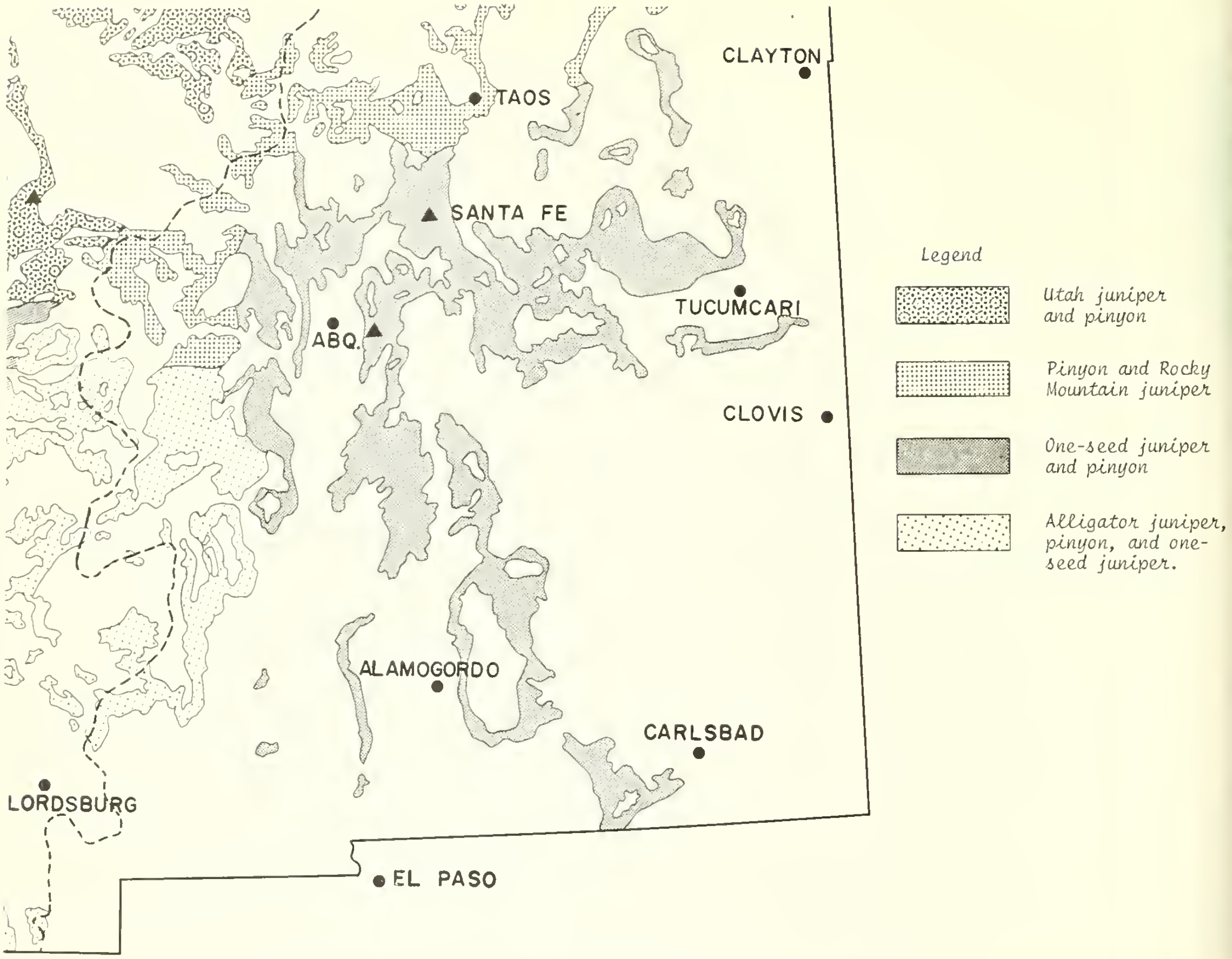

Figure 1.--Distribution of pinyon-juniper in New Mexico.

There are over 120 geologic types identified in New Mexico, almost half of which occur in the woodland type. Many have been consolidated into broad categories in this Note (table 2).

Thirty-two percent of the National Forest system lands in New Mexico support the pinyon-juniper type (table 1). On the five Forests entirely within the State, over 24 percent of each Forest is in this type. On the Cibola, 46 percent of the Forest is classed as woodland.

Almost 29 percent of the pinyon-juniper type is on highly unstable geologic formations that contribute to high sediment yields (table 2). Sedimentary units make up 54 percent of the acreage in the type, igneous units 39 percent, and Pre-Cambrian formations 7 percent.

Older alluvium, sandstones, the Datil formation, and volcanics each make up over 10 percent of the acreage in woodland. The Datil formation, a high sediment producer, makes up 27 percent of the Cibola National Forest woodland and 42 percent of the Gila National Forest woodland type (table 2).

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 198

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Basal Area Growth of Arizona Mixed Conifer Species

Robert S. Embry and Gerald J. Gottfried[1]

Growth data were collected from four small mixed conifer watersheds totaling 1,800 acres in east-central Arizona. Annual gross basal area increment was estimated to be 4.027 square feet per acre. This represents a 2.3 percent annual increase.

KEY WORDS: Stand increment estimates, basal area measurement, mixed conifer forests.

Mixed conifer stands occupy about 6 per-ent of the commercial forest land in Arizona. he areas they occupy, however, are some of he most productive lands in the State. These nixed conifer forests are mostly uncut, all-aged tands of Engelmann spruce (Picea engel-nannii), blue spruce (Picea pungens), Douglas-ir (Pseudotsuga menziesii), white fir (Abies oncolor), corkbark fir (Abies lasiocarpa var. rizonica),[2] ponderosa pine (Pinus ponderosa), outhwestern white pine (Pinus strobiformis), nd quaking aspen (Populus tremuloides) in a vide variety of mixtures.

Large-scale harvesting of these mixed stands egan in 1966. Optimum management practices ave not yet been fully established. Growth nformation needed to prescribe satisfactory imber and watershed management practices is ot available for these mixed species.

This Note presents data that will provide means of estimating gross basal area and olume growth in mixed conifer stands.

Procedures

Growth data were obtained during an overstory inventory of about 1,800 acres of virgin mixed conifer forests on the four Willow-Thomas Creek watersheds on the Apache National Forest in east-central Arizona. This inventory was made according to methods developed by Ffolliott and Worley.[3] Increment borings were taken from one tree out of every four selected with a 25 BAF angle gage for diameter measurement. Growth information was collected from 991 trees on 556 sample points. Average annual gross basal area increment (BAI) for each d.b.h. class was computed from the increment core measurements. The distribution of sample trees by species is shown below:

Species	Number of trees
Douglas-fir	277
Ponderosa pine	172
White fir	155
Quaking aspen	121
Engelmann spruce	118
Southwestern white pine	100
Blue spruce	24
Corkbark fir	24
Total	991

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[1] *Embry is Associate Silviculturist, lo-ated at Flagstaff in cooperation with North-rn Arizona University; Gottfried is Associate ydrologist, located at Tempe in cooperation ith Arizona State University. Station's cen-ral headquarters is maintained at Fort Col-ins in cooperation with Colorado State niversity.*

[2] *On the Kaibab Plateau, corkbark fir is eplaced by subalpine fir (Abies lasiocarpa ar. lasiocarpa (Hook.) Nutt.).*

[3] *Ffolliott, Peter F., and David P. Worley. An inventory system for multiple use evaluations. U. S. Forest Serv. Res. Pap. RM-17, 15 p. 1965. Rocky Mt. Forest and Range Exp. Sta., Ft. Collins, Colo.*

A basal area stand table was constructed from the basic inventory data by conventional point-sampling techniques (table 1).

Results

Basal area increment.—The sapling-small pole size class accounts for almost half the total gross BAI of 4.027 square feet per acre per year (table 2). One-third of the total is produced by Douglas-fir.

The large standard errors associated with the sapling-small pole class are the result of converting basal area per acre to number of trees per acre in the double-sampling procedure to compute BAI. The smaller the diameter, the larger the number of trees it represents on a per-acre basis.

Basal area growth percentage.—The total gross annual BAI of 4.027 square feet per acre represents a 2.3 percent annual increase. The sapling-small pole class shows the greatest class increase with 6.7 percent (table 3). Corkbark fir has the greatest species increase, with 3.7 percent.

Application of Results

The prediction of growth is necessary for the formulation of any management plan. Growth percentage provides a quick, simple, and relatively accurate method of predicting growth.

Volume growth is a function of basal area and height increment plus any changes in form. Volume growth may be a function of basal area increment alone in mature trees, in which height and form change very slowly. Such a condition would be restricted to the larger size classes in the mixed conifers.

If a short prediction period of 5 to 10 years is used and a precise estimate is not required, the growth percentages in table 3 may be used for all size classes. The volume in each species-size class multiplied by the respective growth percentage gives a useful and quick estimate of gross annual volume growth. At present we have total cubic-foot volume tables only for ponderosa pine. When such information becomes available for the other species, these growth percentages may be used.

The growth percentage method must be used with caution. Davis[4] states that ". . . the main difficulty with growth percent as a management tool is that it is not a quantity, but a relationship with all the shifty characteristics of percentages in general." Growth percentages vary by species, diameter class, and prediction period and are not constant for any stand, especially a natural, mixed stand.

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[4] *Davis, K. P. American Forest Management. p. 98. N. Y.: McGraw-Hill Book Co., Inc. 1954.*

Table 1.--Basal area per acre on an 1,800-acre mixed conifer stand in east-central Arizona

Size class	Douglas-fir	Quaking aspen	White fir	Ponderosa pine	Engelmann spruce	White pine	Corkbark fir	Blue spruce	Total
	Square feet								
Sapling-small poles (0.1-6.9 inches)	8.45	6.92	3.55	2.43	3.51	1.57	1.03	0.45	27.91
Poles (7.0-10.9 inches)	6.56	12.41	2.74	1.26	5.44	1.71	1.89	.63	32.64
Small sawtimber (11.0-16.9 inches)	11.38	7.15	3.69	3.87	9.22	2.43	2.16	1.03	40.93
Medium sawtimber (17.0-22.9 inches)	10.39	1.66	4.50	7.15	4.41	1.80	.63	.76	31.30
Large sawtimber (23.0 inches plus)	18.97	.04	11.38	10.30	1.44	2.43	.22	.18	44.96
Total	55.75	28.18	25.86	25.01	24.02	9.94	5.93	3.05	177.74
	Percent								
Distribution	31	16	14	14	14	6	3	2	

Table 2.--Gross annual basal area increment per acre on an 1,800-acre mixed conifer stand in east-central Arizona (Confidence intervals are at the 95 percent level)

Size class	Douglas-fir	Quaking aspen	White fir	Ponderosa pine	Engelmann spruce	White pine	Corkbark fir	Blue spruce	Total	Distribution
	Square feet									Percent
apling-small poles (0.1-6.9 inches)	0.687±.214	0.262±.077	0.203±.084	0.188±.146	0.266±.140	0.105	0.125	0.043	1.879	47
oles (7.0-10.9 inches)	.147±.041	.340±.095	.061±.023	.027±.012	.133±.045	.061±.024	.047±.031	.016	.832	21
mall sawtimber (11.0-16.9 inches)	.193±.038	.126±.035	.053±.023	.060±.021	.185±.046	.035±.013	.040±.020	.016±.011	.708	17
edium sawtimber (17.0-22.9 inches)	.094±.021	.019	.049±.014	.066±.017	.054±.017	.020±.006	.006	.009±.006	.317	8
arge sawtimber (23.0 inches plus)	.120±.018	<.001	.080±.017	.059±.011	.012±.006	.015±.006	.001	.004	.291	7
Total	1.241	.747	.446	.400	.650	.236	.219	.088	4.027	
	Percent									
istribution	31	19	11	10	16	6	5	2		

Blocked-in values are means of four or fewer sample trees expanded to a per-acre value. Intervals could not be calculated ecause of insufficient data.

Table 3.--Annual gross basal area growth percentage for mixed conifers in 1,800-acre stand in east-central Arizona

Size class	Douglas-fir	Quaking aspen	White fir	Ponderosa pine	Engelmann spruce	White pine	Corkbark fir	Blue spruce	Average[1]
	Percent								
Sapling-small poles (0.1-6.9 inches)	8.1	3.8	5.7	7.8	7.6	6.7	12.1	9.4	6.7
Poles (7.0-10.9 inches)	2.2	2.7	2.2	2.1	2.4	3.6	2.5	2.6	2.5
Small sawtimber (11.0-16.9 inches)	1.7	1.8	1.4	1.5	2.0	1.4	1.8	1.6	1.7
Medium sawtimber (17.0-22.9 inches)	.9	1.1	1.1	.9	1.2	1.1	1.0	1.2	1.0
Large sawtimber (23.0 inches plus)	.6	1.0	.7	.6	.8	.6	.6	2.0	.6
Average[1]	2.2	2.6	1.7	1.6	2.7	2.4	3.7	2.9	[1]2.3

[1] Averages are derived from tables 1 and 2; i.e., $\frac{4.027 \text{ (table 2)}}{177.74 \text{ (table 1)}} = 2.3$ percent.

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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Moisture Content Calculations for the 100-hour Timelag[1] Fuel in Fire Danger Rating

Michael A. Fosberg[2]

The 100-hour timelag fuel moisture content is computed from the daily moisture exchange factor and precipitation duration. The computational method is presented in tabular form for quick and easy field use.

KEY WORDS: Forest fuels, forest fire hazard, forest fuel moisture, climatology.

Fire control agencies need moisture contents f the large fuels for evaluation of energy re-ease. Traditionally, this has been taken care f by a buildup index.

Buildup fuel moisture or its associated build-p index generally are not determined by direct neasurement in the field. Early attempts o express the contribution of this fuel to fire ehavior were based on calendar date or days ince rain and amount of rain (Gisborne 1936, emison et al. 1949). Improvements were made uring the 1950's with the introduction of a uildup index based on fine fuel moisture nd amount of rain (Keetch 1954, Nelson 1955, Jenson and Schroeder 1958). The buildup index was first related to specific fuels and moisture content in the Wildland Fire Danger System (Jenson and Schroeder 1958) which casually related the buildup to moisture content of 6-inch logs. This fuel has a timelag of approximately 1000 hours.

More recently, the Forest Service[3] developed a buildup index for a fuel with a 120-hour timelag.[4] This index was also based on fine fuel moisture and precipitation amount.

Both of these buildup indices can, in principle, reach very high values. This introduces a complicating feature in relating the buildup value to fuel moisture: As the buildup becomes large, changes in buildup do not reflect corresponding changes in fuel moisture, thus

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[1] *Timelag is defined as the time interval n which the fuel loses approximately two-hirds of its moisture content above equilib-ium (actually 1 - 1/e, where e is the base of apierian logarithms) under standard drying onditions of 20 percent relative humidity and 0° F. A 100-hour timelag fuel takes 100 hours o lose approximately two-thirds of its mois-ire under standard drying conditions.*

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[3] *U. S. Forest Service. 1966. Derivation of spread phase tables - national fire-danger rating system. Division of Fire Control, 54 p. (Unpublished.)*

[4] *The timelag value given was 240 hours. However, the drying was not under standard conditions. For an explanation of why it should be 120 hours, see Fosberg et al. (1970) and Johnson (1968).*

a linear relationship is not maintained in all ranges. A second drawback of these systems is that they are only indirectly related to fuels.

During the 1930's and early 1940's, an alternate procedure was introduced. The then Northern Rocky Mountain Forest and Range Experiment Station worked with 2-inch dowels and duff hygrometers (Gisborne 1936). These allowed a direct measurement of the condition of the buildup fuel. The timelag associated with the 2-inch dowel is approximately 200 hours. The timelag for the layer measured by the duff hygrometer is not known, although it is probably near 10 hours if work done elsewhere (Johnson 1968) is extrapolated to thin layers. This direct measurement of fuel moisture has distinct advantages over buildup indices. It relates buildup to a specific fuel.

Current developments in a National Fire Danger Rating System have followed this approach. Dead fuels are classified into the three groups of 1-, 10-, and 100-hour timelag classes.[5] The 100-hour timelag class has a size of 1- to 3-inch diameter, and corresponds well with the buildup index used in the 1964 spread index tables and with the 2-inch dowels used during the 1930's and early 1940's. The timelag, through the Fourier number, contains information on size and physical characteristics such as species of the fuel, so that a computation system may be related directly to a specific fuel. This solves the second problem. A solution to the first problem, that of maintaining a linear relationship between the computational system and fuel moisture, is presented in the following section.

Theory of the Computational System

Drying and wetting of fuels takes place only at their surface. Moisture movement within the fuel does not affect the overall moisture content, but merely redistributes moisture so that it may be lost from the surface at varying rates. If the accumulated moisture is near the surface of the fuel it may be readily lost, but if it is distributed rather uniformly within the fuel or if it is near the center, the loss rate is less. A theoretical solution based on this fact[6] is used in this computational system.

The change of moisture content for transien surface conditions is

$$\frac{\delta m}{\Delta m} = 1 - \zeta e^{-\lambda t} \qquad (1$$

where the relationship between change in moisture content, $\delta m = m - m_i$, and the differenc between the surface moisture content and th initial moisture content, $\Delta m = m_b - m_i$, is simple exponential function. In this expressio m is the moisture content at the end of th change period, m_i is the moisture conten at the beginning, and m_b is the moistur content of the surface fibers. During a dryin process, the surface moisture content is take as equilibrium moisture content. During rainfall, however, this moisture content is rate an time dependent. If the discussion is limite to branch wood, precipitation rate may b neglected because of the limiting rate at whic liquid water is absorbed into the wood. Thus the wetting of stem and branch wood is dependent only on the duration of the rainfall. These assumptions prohibit use of this syste in duff and litter.

The right side of equation (1) has bee obtained from both linear analytical theor and nonlinear numerical experiments, with excellent agreement between them.

For the 100-hour timelag fuel, the similarit coefficient $\zeta = 0.7547$, the inverse of the time lag $\lambda = 0.01$, and t is either the length of th drying period or the duration of the rain i hours.

Field Application

To apply the results of this computation system conveniently in the field, the solutio of the equation is presented in tabular form

Table 1 expresses the relationship betwee actual field drying conditions and standar drying conditions. The inputs to table 1 ar daily average temperature, and average humi ity. These may be obtained from the max mums and minimums of temperature and humi ity. The output from table 1 is the moistur exchange factor which is basically the rati of equilibrium moisture content under standar drying conditions to field equilibrium cond tions. The moisture exchange factor is obtaine from the equilibrium moisture content iso therms in the Wood Handbook (1955). Tabl 2 gives the moisture content change for th previous 24 hours due to changes in equilibriu moisture content. The entries into table are yesterday's 100-hour timelag fuel moistur content and the moisture exchange factor fo the previous 24 hours. If precipitation occurre

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[5] *Fosberg, Michael A., Mark J. Schroeder, and James W. Lancaster. Characterization of dead forest fuels by moisture timelag (manuscript in preparation).*

[6] *Fosberg, Michael A. Theory of precipitation effects on dead cylindrical fuels (in press).*

Table 1.--Moisture exchange factor[1]

Average relative humidity	Average temperature (degrees F.)						
	<40	40 ↓ 49	50 ↓ 59	60 ↓ 69	70 ↓ 79	80 ↓ 89	90 ↓ 100
<7	2.00	2.00	2.00	2.00	2.00	2.00	2.00
8→12	1.80	1.80	1.80	1.80	2.00	2.00	2.00
13→17	1.20	1.20	1.20	1.20	1.20	1.20	1.40
18→22	1.00	1.00	1.00	1.00	1.00	1.00	1.20
23→27	.80	.80	.80	.85	.85	.85	.90
28→32	.70	.70	.70	.70	.75	.75	.80
33→37	.60	.60	.65	.65	.65	.70	.70
38→42	.55	.55	.55	.60	.60	.60	.60
43→47	.50	.50	.50	.55	.55	.55	.55
48→52	.45	.45	.45	.50	.50	.50	.50
53→57	.40	.45	.45	.45	.45	.45	.45
58→62	.40	.40	.40	.40	.40	.40	.45
63→67	.35	.35	.35	.40	.40	.40	.40
68→72	.35	.35	.35	.35	.35	.35	.35
73→77	.30	.30	.30	.30	.30	.30	.30
78→82	.25	.25	.30	.30	.30	.30	.30
83→87	.25	.25	.25	.25	.25	.25	.25
88→92	.20	.20	.20	.20	.20	.25	.25
93→97	.15	.15	.20	.20	.20	.20	.20
>98	.15	.15	.15	.15	.15	.15	.15

[1] If precipitation has been continuous for past 24 hours, do not use table 1 or table 2. Use table 3 only to calculate change in 100-hour timelag moisture content.

uring the previous 24 hours, table 3 is used ı addition to table 2. The entries into table are yesterday's moisture content and the uration of precipitation. The change obtained ı table 3 is then algebraically added to the hange from table 2; this result is then added) or subtracted from yesterday's moisture content to give today's moisture content.

As an example, assume yesterday's fuel ıoisture content was 20 percent. The maxiıum and minimum temperature during the revious 24 hours were 72° and 50° F., espectively, and the maximum and minimum elative humidities were 80 percent and 12 ercent. No precipitation occurred during the ast 24 hours. From this, the computation as follows:

$$\text{average temperature} = \frac{72 + 50}{2} = 61$$

$$\text{average humidity} = \frac{80 + 12}{2} = 46$$

By entering an average temperature of 61 and an average humidity of 46 into table 1, the moisture exchange factor is found to be 0.55.

Since yesterday's moisture content was 20 percent and the moisture exchange factor was 0.55, these values are entered into table 2 to find the change for the previous 24 hours. This gives a change of -4 percent.

No precipitation occurred so table 3 is ignored. Thus, today's fuel moisture content is

$$20 - 4 = 16 \text{ percent.}$$

Consider a second example. Yesterday's fuel moisture content was 7 percent; maximum and minimum temperatures were 57° and 43° F.,

Table 2.--Change in 100-hour timelag moisture content (percent) due to change in moisture exchange factor[1]

Moisture exchange factor	Yesterday's 100-hour timelag moisture content (percent)																
	1 ↓ 2	3 ↓ 5	6 ↓ 10	11 ↓ 15	16 ↓ 20	21 ↓ 25	26 ↓ 30	31 ↓ 35	36 ↓ 40	41 ↓ 45	46 ↓ 55	56 ↓ 65	66 ↓ 89	90 ↓ 109	110 ↓ 129	130 ↓ 164	165 ↓ 199	200
.15	11	11	9	7	5	3	1	0	2	4	8	12	18	26	35	47	63	69
.20	8	8	6	4	2	0	2	3	5	7	11	15	21	30	38	50	66	72
.25	6	6	4	2	0	2	4	5	7	9	13	17	23	31	40	52	68	74
.30	5	4	3	0	1	3	5	6	8	10	14	18	24	33	41	53	69	75
.35	4	4	2	0	2	4	6	7	9	11	15	19	25	33	42	54	70	76
.40	4	3	2	1	3	5	7	7	10	12	16	20	26	34	42	54	71	77
.45	3	2	0	2	3	5	7	8	10	12	16	20	26	35	43	55	71	77
.50	3	2	0	2	4	6	8	9	11	13	17	21	27	35	43	55	72	78
.55	3	2	0	2	4	6	8	9	11	13	17	21	27	35	43	56	72	78
.60	2	1	0	3	4	6	8	9	11	13	17	21	27	36	44	56	72	78
.65	2	1	0	3	5	7	9	9	11	13	18	22	28	36	44	56	72	78
.70	2	1	0	3	5	7	9	10	12	14	18	22	28	36	44	56	73	79
.75	2	0	1	3	5	7	9	10	12	14	18	22	28	36	44	56	73	79
.80	1	0	1	3	5	7	9	10	12	14	18	22	28	36	44	57	73	79
.85	1	0	1	4	5	7	9	10	12	14	18	22	28	36	45	57	73	79
.90	1	0	1	4	5	7	9	10	12	14	18	22	28	37	45	57	73	79
1.00	1	0	1	4	6	8	10	10	12	14	18	23	29	37	45	57	73	79
1.20	1	0	2	4	6	8	10	11	13	15	19	23	29	37	45	57	74	80
1.40	0	0	2	4	6	8	10	11	13	15	19	23	29	37	45	58	74	80
1.80	0	1	2	5	6	8	10	11	13	15	19	23	29	38	46	58	74	80
2.00	0	1	2	5	7	8	10	11	13	15	19	23	30	38	46	58	74	80

[1] Numbers within the shaded area are positive (+), those in the unshaded area are negative (-)

maximum and minimum humidities were 100 and 60 percent, and a rain shower lasted 2 hours:

$$\text{the average temperature is } \frac{57 + 43}{2} = 50$$

$$\text{the average humidity is } \frac{100 + 60}{2} = 80$$

which gives a moisture exchange factor from table 1 of 0.3.

Since yesterday's moisture content was 7 percent and the drying power was 0.3, table 2 gives today's change as +3 percent.

The 2 hours of rain require that table 3 be used. Entering the precipitation duration and yesterday's moisture content, the change is +6 percent.

Thus, today's fuel moisture content is

$$7 + 3 + 6 = 16 \text{ percent.}$$

Because the tables are grouped by moistu content ranges and the change values are f the midpoints of the ranges, the tables m yield moisture contents of less than 0 or great than 200 percent. If this happens, the appr priate value of 0 or 200 should be substitute since the fuel would have reached the extren before the end of the 24-hour period. (maximum moisture content of 200 percent wa arbitrarily chosen since it would apply in near all cases.) If precipitation occurs for the enti 24-hour period, table 2 should be bypass since the fuel was being wetted continuall The moisture content at the beginning of computational period may be obtained by b ginning the computation 2 weeks before th numbers are needed, and by use of an "educated guess" of the starting moisture conten After a 2-week period, the initial choice moisture content will not affect the compute values.

Table 3.--Change in 100-hour timelag moisture content (percent) due to precipitation[1]

Duration of precipitation (to closest hour)[2]	Yesterday's 100-hour timelag moisture content (percent)								
	1 ↓ 2	3 ↓ 5	6 ↓ 10	11 ↓ 15	16 ↓ 20	21 ↓ 25	26 ↓ 30	31 ↓ 35	>35
1	7	7	6	4	3	2	1	0	0
2	8	7	6	4	3	2	1	0	0
3	8	7	6	5	3	2	1	0	0
4	8	8	7	5	4	2	1	1	1
5	9	8	7	5	4	3	1	1	1
6	9	8	7	5	4	3	1	1	1
7	9	9	8	6	4	3	2	1	1
8	10	9	8	6	5	3	2	1	1
9	10	9	8	6	5	4	2	1	1
10	11	10	9	7	5	4	2	2	2
11	11	10	9	7	6	4	2	2	2
12	11	11	9	7	6	4	3	2	2
13	12	11	10	7	6	5	3	2	2
14	12	11	10	7	6	5	3	2	2
15	12	11	10	8	6	5	3	2	2
16	13	12	11	8	7	5	3	3	3
17	13	13	11	9	7	6	4	3	3
18	14	13	12	9	8	6	4	3	3
19	14	13	12	9	8	6	4	4	4
20	15	14	12	10	8	6	5	4	4
21	15	14	13	10	9	7	5	4	4
22	16	15	13	10	9	7	5	4	4
23	16	15	14	11	9	7	5	5	4
24	16	15	14	11	10	8	6	5	5

[1] All numbers are positive, but when added to yesterday's 100-hour timelag fuel moisture, the total should not exceed 200.0.

[2] If duration is 30 minutes or less and amount is a trace, no change should be made.

A Field Example

Data from the Colorado State University veather station for August and September were ised to calculate the moisture content of the 00-hour timelag fuel. These data were supplenented with moisture data from 2-inch-diameter onderosa pine (Pinus ponderosa Laws.) dowels 8 inches long and from standard half-inch fuel noisture sticks of ponderosa pine. Comparison f the moisture data with computed fuel moisture fig. 1) shows that the day-to-day changes f the half-inch sticks are greater than those omputed for 100-hour timelag fuel, and those or the 2-inch sticks are less. This relation hould be expected, since the half-inch sticks have a timelag of 12 hours, and the 2-inch sticks have a timelag near 200 hours.

There are two features which prevent complete agreement between the observations and the theoretical solution. The first is that the equilibrium moisture content between the three fuels is different. The theoretical values are based on the equilibrium moisture content in the Wood Handbook (1955). These values are averages for a large number of woods, and they mask the natural variability between samples. The second drawback is that the data for computation were taken from the standard instrument shelter and not from the vicinity of the fuels. Despite these two drawbacks, the computed values are reasonable and the predictions are reasonably correct.

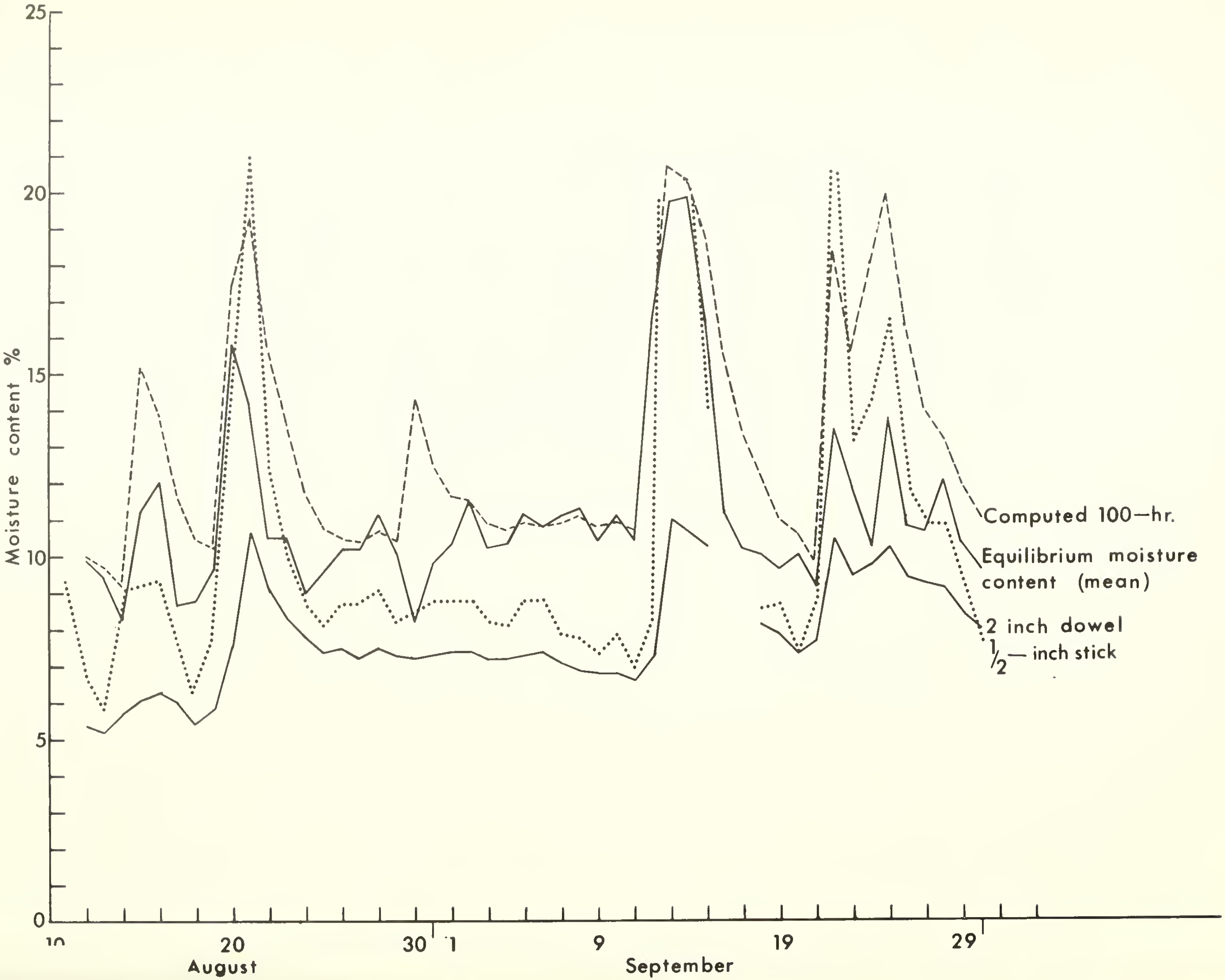

Figure 1.--Observed 10- and 200-hour timelag fuel moisture compared with computed 100-hour timelag and mean equilibrium moisture content.

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U S D A FOREST SERVICE
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DAMID:
A Discounting Analysis Model for Investment Decisions

Michael Gieske and Ronald S. Boster[1]

A computer program discounts benefit and cost flows over time for up to 10 user-determined interest rates, and permits combining flows of differing lengths. Outputs of the program include discounted (present) values of individual costs or benefits, a summed net present value for an entire project (set of flows), and interpolated values for years for which no data are supplied.
KEY WORDS: Discounting, multiple use management.

Multiple use resource management produces everal differing benefit and cost flows over me. Some flows, such as water and sediment, re fairly constant over time; timber harvests ccur periodically at lengthy intervals; conersion of chaparral stands to grasslands reuires consideration of cyclical benefits and osts associated with maintenance operations.[2]

To determine project efficiency, year-to-year enefit and cost variations must be aggregated) single values. The most common represenitions of project benefits and costs are annuity nd present value. Conversion of cyclical, linear, and/or irregular flows to either present value or annuity value makes project evaluation easier.

Values are discounted by using an appropriate rate of interest. Procedures and formulas for discounting are well known.[3]

Use of present value and annuity tables is commonplace in resource evaluations. When several different cost and benefit streams are to be discounted over many years, however, the advantage of a digital computer becomes evident. An additional advantage of the computer is the assurance of consistently precise use of the correct formulas and procedures.

The Discounting Analysis Model for Investment Decisions (DAMID) will perform all types of discounting—one-time, constant, and cyclical—and will also discount data which vary with time, and only after long periods of time. Users may specify up to 10 discount rates for each run.

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[1] *Economists, Rocky Mountain Forest and nge Experiment Station, located at Tucson, cooperation with University of Arizona; ation's central headquarters maintained at rt Collins, in cooperation with Colorado ate University. Gieske is currently Research sociate, Department of Economics, Iowa State iversity, Ames.*

[2] *O'Connell, Paul F., and Ethel Mathews. plication of economic principles to chaparl management in the Southwest. (In preparaon for publication, Rocky Mountain Forest d Range Experiment Station, Fort Collins, lorado).*

[3] *Lundgren, Allen L. Tables of compound-discount interest rate multipliers for evaluating forestry investments. USDA Forest Serv. Res. Pap. NC-51, 142 p. 1971. North Central Forest Exp. Sta., St. Paul, Minn.*

DAMID computes the present value of each cost or benefit stream for perpetuity as well as for a specified project life up to 151 years, and also determines the appropriate annuity over the project life. All flows are added and printed as net present values and net annuities for each specified discount rate.

The program will evaluate monetary streams which vary in repetitive cycles, such as maintenance costs and those benefits which vary in response to the maintenance patterns. Only one complete cycle need be specified; the model will evaluate the stream as though the cycles continued over the project life and in perpetuity.

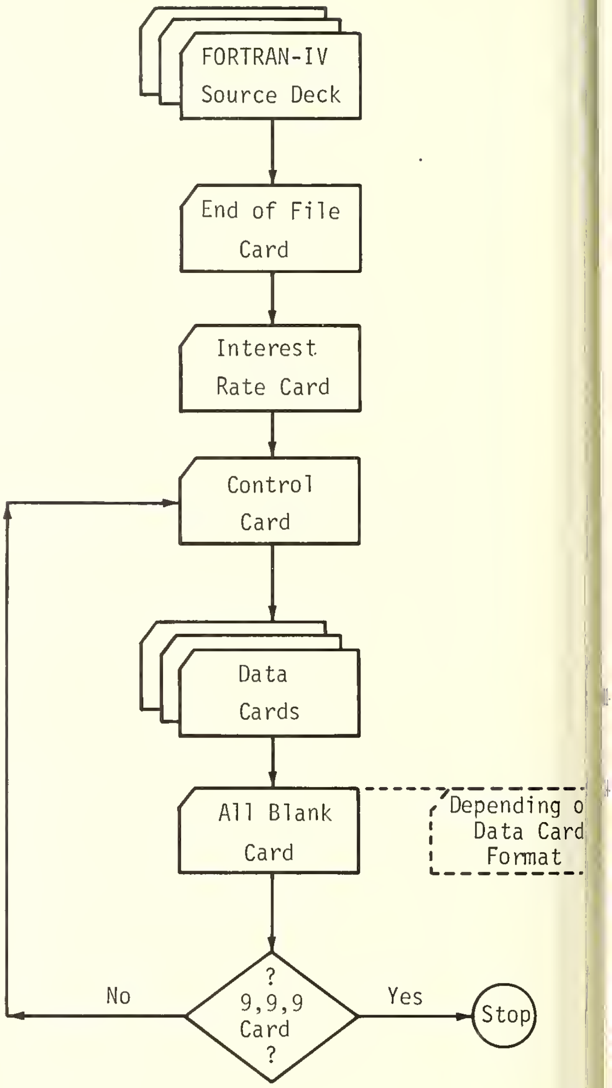
The user need not specify data for each year of a particularly lengthy stream. Values may be entered for some of the years, and the model instructed to interpolate between any two given points. Specification options include linear (equal-sized changes), convex (early changes larger than later changes), and concave interpolations (early changes smaller than later changes).

Entered flow values may represent either monetary or physical quantities. Each entry is multiplied by one of four scaling factors: price per unit, an updated price index, area (if data are entered on a per-acre basis, for example), or unity. If no factor is specified, the unity scaling factor is assumed. The scaling feature adds flexibility to the model by eliminating the need to repunch data cards when varying price, quantity, or project size.

The following sections give the instructions for using DAMID, along with a complete program listing. The Program Detail is divided into three parts: explanation of the interpolation mathematics, sample output with descriptive comments, and a complete DAMID FORTRAN listing.

CARD SEQUENCE

The first card after the FORTRAN Extended source deck and appropriate end-of-file card (for example, 7/8/9 multi-punch on many systems) is the interest rate, or **discount rate card.** A **control card** is next followed by the **data cards** which are followed by an **all-blank card.** In some cases, discussed below, the all-blank card is not used. Additional data flows may be added by repeating this sequence beginning with a new control card. A card with 9's in columns 1, 2, and 3 signals th end of data input. The proper card sequenc is as follows:



CARD FORMATS

Discount Rate Card

Format is 10F8.7

Up to 10 interest rates may, therefore be punched on the card. However, only on discount rate card is allowed. Rates may b expressed either as 0 + i or 1 + i, for example 0.06 or 1.06.

Control Card

Columns	Format	Field Name	Narrative
1-10	I10	Project Number	A nonzero number must be entered on the first control card. Thereafter, the project number is optional; if omitted, the program assumes the project number last read. No project may begin with 999. All flows with the same project number must be in consecutive order because computations and output operations are performed whenever a new project number is encountered.
11-13	I3	Flow Number	Optional
14-16	I3	Project Life	The project life entry is necessary. The following restrictions apply: 1) Maximum project life is 151 years. 2) The number of values for any one flow must not be greater than the project life. 3) The project life must be the same for all flows within a project.
17-19	(This field is unused)		
20	I1	Read Format Indicator	A 0 or 1 will read data year-by-year with an F8.2 format. If a 2 is encountered, data are read by an I3, F7.2 format wherein each value (F7.2) is identified by a year number (I3). Data card format options are described in the following section.
21-23	I3	Cycle Start Indicator	This entry marks the beginning of **cyclical (repeating) data.** The cycle length is determined as follows: DAMID locates the last nonzero value entered, subtracts the cycle start year, and then adds one. For example, if the last nonzero value is in year 10 and the cycle starts in year 7, the length of the cycle is 10 - 7 + 1 = 4 years. Therefore, if a cycle ends in zero, the user must enter a small number (e.g. 0.00001) as the last value of the cycle rather than entering zero. For **noncyclical (nonrepetitive) data,** a number greater than the number of values in the entire flow must be entered.
24-29	(This field is unused)		

30	I1	Interpolation Flag	0 = interpolation 1 = no interpolation 9 = interpolation plus interpolated values are printed. For **one-time costs or benefits,** interpolation must be suppressed by a 1 in column 30.
31-40	10I1	Interpolation Form	1 = linear 2 = convex (largest changes in earlier years) 3 = concave (largest changes in later years) There is never any interpolation between year zero and the first nonzero value. Each I1 field is linked to the order of nonzero interpolation. For example, the first year(s) with no value and between years with positive values will have values computed based on the interpolation form specified in column 31. If more than 9 interpolations are required, DAMID uses the interpolation form specified in column 40 for the 10th and subsequent interpolations. The mathematics of the interpolation forms is described later.
41-80	4F10.0	Scaling Factors	Columns 41-50—Price Columns 51-60—Area Columns 61-70—Quantity Columns 71-80—Constant Use of scaling factors is optional; a blank field will cause the program to assume the value 1. However, all succeeding flows will use the specified factor unless reset. For example, if a scaling factor consists of Price = 1.5 and Quantity = 3000, it would be necessary to punch a 1.0 for each in the next flow to avoid scaling succeeding flows by 4500. Minus signs for cost data may be omitted by setting the price scaling factor equal to -1.0.

Data Cards

Two format options are available: 10F8.2 for year-by-year data, and 8(I3, F7.2) for isolated year data or for data requiring interpolation (the I3 corresponds to the year—through 150— and the F7.2 is the value for the year). In the former, at least one word per card **must** be nonzero. In the latter, points used for interpolation must be nonzero.

All-Blank Card

An all-blank card must follow the last data card **if and only if:**

1) The 10F8.2 data input format (year by year) is used.
2) All 8 words of the 8(I3,F7.2) data input format are used.

nd-of-Data Card (9,9,9 Card)

End of data is indicated by a 9,9,9 card
punch in columns 1, 2, and 3).

PROGRAM DETAIL

Interpolation Mathematics

A useful feature of DAMID is the inter-
lation options which allow users to enter
wer values of quantities than would other-
se be necessary. The mathematics of the
terpolation options is briefly discussed here.
ould the reader desire greater detail, he
ould refer to the DAMID subroutine
ALRED2 .

Three forms of interpolation are available:
near, convex, and concave. The essential
athematics of each follow. For notation pur-
ses, assume interpolation is between years
and B (A<B) and that the (undiscounted)
lue or cost for year i is V(i).

near Interpolation

Each V(i) between A and B is found as follows:

$$V(i) = i * SLOPE + V(A)$$

where $SLOPE = (V(B) - V(A) / (B - A)$.

nvex Interpolation

Each V(i) between A and B is found as follows:

$$V(i) = (SIN(i/(B - A)) * K) * (V(B) - V(A)) + V(A)$$

where $K = 1.5707961268$ radians

$= \pi/2$ radians $= 90°$

Concave Interpolation

Each V(i) between A and B is found as follows:

$$V(i) = (1.0 - (COS(i/(B - A)) * K) * (V(B) - V(A)) + V(i)$$

where K is as above.

Sample Output

DAMID output formats were written to provide users with a concise computational summary. The sample output presented here is intended to illustrate the general nature of the printout formats. A hypothetical benefit and cost flow was submitted. Interpolation features were not used.

Although most of the printout is self-explanatory, some explanations are in order. "PV" is "present value." The difference between "PV OF FLOW" and "PV FOR LIFE" is that the former excludes repetitive data, that is, only data up to the beginning of a cycle (if any) are considered, whereas the latter includes both repetitive and nonrepetitive data. Consequently, as in the case of no cyclical data, "PV OF FLOW" and "PV FOR LIFE" can be equal. The comparison of these two columns can often provide useful information concerning the impact of time-distant cycles.

The "PERIOD NUMBER" and "VALUE READ" columns are not associated with adjacent columns. These two columns enable the user to quickly review up to the first 10 years of data (the number of "review" years is equal to the number of interest rates specified). Values for period "zero" are not discounted because such values occur during the first year of analysis. In the sample output shown, the 856.0 for flow number 1 was read as a first-year value (period number 0) and would not be discounted by program. The value -856.0 for flow number 2 (a cost flow as evidenced by the negative numbers), however, would be discounted because this value is for the second year (period number 1). The flows submitted for the sample output are:

Flow 1 (Benefits)		**Flow 2** (Costs)	
Year	Value	Year	Value
1	856.0	1	-900.5
5	900.0	3	-856.0
15	1,000.3	9	-1,000.0
16	882.33	39	-800.5
61	3,384.0	61	-502.3

```
FLOW    INTEREST         PV OF              PV FOR              PV INTO              ANNUAL          PERIOD            VALUE
NUMBER  RATES            FLOW               LIFE                PERPETUITY           EQUIVALENT      NUMBER            READ
---     -------      ------------       ------------        ------------         ------------     ---           ------------
  1     1.05000        2708.3241          2708.3241           2708.3241            140.0181        0              856.0000
  1     1.06000        2483.0310          2483.0310           2483.0310            151.5472        1                0.0000
  1     1.07000        2309.5870          2309.5870           2309.5870            163.1019        2                0.0000
  1     1.08000        2170.4116          2170.4116           2170.4116            174.4308        3                0.0000
NUMBER OF VALUES READ IS  61,REPETITION OF VALUES BEGINS IN PERIOD  80, AND LENGTH OF THE CYCLE IS  0.
  THE MULTIPLYING FACTOR IN USE IS              1.000000.


  2     1.05000       -2506.0101         -2506.0101          -2506.0101           -129.5586        0             -900.5000
  2     1.06000       -2392.4219         -2392.4219          -2392.4219           -146.0170        1                0.0000
  2     1.07000       -2300.0447         -2300.0447          -2300.0447           -162.4281        2             -856.0000
  2     1.08000       -2222.5908         -2222.5908          -2222.5908           -178.6244        3                0.0000
NUMBER OF VALUES READ IS  61,REPETITION OF VALUES BEGINS IN PERIOD  80, AND LENGTH OF THE CYCLE IS  0.
  THE MULTIPLYING FACTOR IN USE IS             -1.000000.




THE DISCOUNT    NET PRESENT VALUES,          NET PRESENT VALUES      SUM OF THE ANNUITIES            NET RETURNS FOR INITIAL
RATES USED       ASSUMING MAINTENANCE         FOR THE PROJECT          FOR ALL FLOWS IN                YEARS OF INVESTMENT    FOR YEAR
ARE            CONTINUES INTO PERPETUITY      LIFE OF 70YEARS             PROJECT                      (NOT DISCOUNTED)       NUMBER
----------      --------------------       ---------------------    --------------------            ---------------------   -------
1.0500000                  202.31                    202.31                  10.46                                -44.50       0
1.0600000                   90.61                     90.61                   5.53                                  0.00       1
1.0700000                    9.54                      9.54                    .67                               -856.00       2
1.0800000                  -52.18                    -52.18                  -4.19                                  0.00       3

INTEREST RATES USED ARE                        1.05000  1.06000  1.07000  1.08000 -0.00000 -0.00000 -0.00000 -0.00000 -0.00000 -0.00000
BENEFIT/COST RATIOS AT EACH DISCOUNT RATE      1.081    1.038    1.004     .977

PROJECT NUMBER IS 4202000001                                                                      4202000001 IS PROJECT NUMBER.
+++++-------------------------------------------------------++ END OF PROJECT ++--------------------------------------------------+++++
```

Complete DAMID FORTRAN Listing

```
C                             DAMID
C      DISCOUNTING ANALYSIS MODEL FOR INVESTMENT DECISIONS
C
C                              BY
C
C              MICHAEL H. GIESKE AND RONALD S. BOSTER
C
C     ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION, TUCSON, ARIZ.
C
C
C
C
      COMMON R(11),PV1(151,10),IR,PVFLO(10),ANN(10),PVPER(10),PVLIF(10),
     1SANN(10),SPVPE(10),SPVLI(10),VAL(151),NVAL,SVAL(10),NFLOW
     2 ,LIFE,LFLOW,ICON(20),ICONT,NPROJ
     3,PVCYC(10),ANCYC(10),PVANL(10),LCYCL
     4,PRICE,QUANT,AREA,CONST,SCALE,COST(10),BC(10)
     5,KEY,VL(8),IND(8)
C
      NPROJ = 0
      NFLOW = 0
      LIFE = 0
      PRICE = 0.0
      QUANT = 0.0
      AREA = 0.0
      CONST = 0.0
      IGARB = 0
C
      CALL PVARRAY
C
      IF(R(1).LT.0.5) STOP
      WRITE(6,140)
  140 FORMAT(1H1,*FLOW    INTEREST         PV OF               PV FOR
     1        PV INTO             ANNUAL          PERIOD           VALUE
     2*)
      WRITE(6,141)
  141 FORMAT(1H ,*NUMBER  RATES             FLOW                LIFE
     1        PERPETUITY          EQUIVALENT      NUMBER           READ*
     2)
      WRITE(6,142)
  142 FORMAT(1H ,*---    -------        ------------        ------------
     1        ------------        ------------     ---          --------
     2----*)
    9 READ(5,10)  (ICON(I), I=1,20),PRC, QNT, ARA, CNST
   10 FORMAT(I10,3I3,I1,I3,3I2,11I1,4F10.0)
      LIF = LIFE
      IF(ICON(3).NE.0) LIFE = ICON(3)
   13 LFLOW = ICON(4)
      IF(ICON(1).EQ.0) ICON(1) = NPROJ
C
C     IF A NEW PROJECT NUMBER IS FOUND, SKIPS TO WRITE OUT SUMS FOR PROJ
C     IF NEW PROJECT NUMBER IS 9990000000 IT WILL WRITE OUT SUMS AND
C     THEN EXIT FROM STATEMENT 22
C
      IGARB = IGARB + 1
   14 IF(ICON(1)-NPROJ) 20,15,20.
   15 IF(ICON(2).EQ.999) GO TO 20
C     HERE TO 18 SELECTS PROPER READ-IN FORMAT AND ROUTINE.
   16 CONTINUE
      IF(ICON(5).LT.2) IFORM = 1
      IF(ICON(5).GT.1) IFORM = 2
   18 GO TO (19,50),IFORM
```

```
   19 CALL VALREAD
      GO TO 51
   50 CALL VALRED2
   51 CONTINUE
C
      IF(NVAL.EQ.0) STOP
      IF(LIFE.EQ.0)  LIFE = NVAL
      IF(PRC.NE.0.0) PRICE = PRC
      IF(QNT.NE.0.0) QUANT = QNT
      IF(ARA.NE.0.0) AREA = ARA
      IF(CNST.NE.0.0) CONST = CNST
      IF(PRICE,EQ.0.0) PRICE = 1.0
      IF(QUANT,EQ. 0,0) QUANT = 1.0
      IF(AREA.EQ.0.0) AREA = 1.0
      IF(CONST,EQ.0.0) CONST = 1.0
      SCALE = PRICE * QUANT * AREA * CONST
      IF(SCALE,EQ.1.0) GO TO 36
      DO 35 N=1,NVAL
   35 VAL(N) = SCALE * VAL(N)
C
   36 CALL COMPUTE
      IF(LCYCL,LT.0) LCYCL = 0
C
      WRITE(6,29) NVAL,KEY,LCYCL
   29 FORMAT(1H ,*NUMBER OF  VALUES READ IS *,I3,*.REPETITION OF VALUES B
     1EGINS IN PERIOD *,I3,*, AND LENGTH OF THE CYCLE IS *,I3,*.*)
      WRITE(6,1129) SCALE
 1129 FORMAT(1H ,*  THE MULTIPLYING FACTOR IN USE IS *,F20.6,*.*,///)
      GO TO 9
C
C     AFTER WRITING SUMS WE ZERO SUMS AND THEN CONTINUE
   20 CONTINUE
      IF (IGARB.EQ.1) GO TO 777
      WRITE(6,110)
  110 FORMAT(1H0,//////////)
      WRITE(6,111)
  111 FORMAT(1H ,*THE DISCOUNT    NET PRESENT VALUES,*,10X,*NET PRESENT
     1VALUES*,5X,*SUM OF THE ANNUITIES*,12X,*NET RETURNS FOR INITIAL*)
      WRITE(6,112)
  112 FORMAT(1H ,*RATES USED*,5X,*ASSUMING MAINTENANCE*,10X,*FOR THE PRO
     1JECT*,9X,*FOR ALL FLOWS IN*,16X,*YEARS OF INVESTMENT   FOR YEAR*)
      WRITE(6,113) LIF
  113 FORMAT(1H ,*ARE*,10X,*CONTINUES INTO PERPETUITY*,7X,*LIFE OF*,I3,
     1 *YEARS*,13X,*PROJECT        *,16X*(NOT DISCOUNTED)     NUMBER*)
      WRITE(6,115)
  115 FORMAT(1H ,*----------     -------------------     --------------
     1-------    --------------------                    --------------------
     2   --------*)
C
  190 DO 194 I=1,IR
      K = I - 1
      WRITE(6,116) R(I),SPVPE(I),SPVLI(I),SANN(I),SVAL(I),K
  116 FORMAT(1H ,F9.7,F25.2,F25.2,F25.2,10X,F25.2,5X,I3)
      IF(COST(I),EQ.0.0) GO TO 194
      BC(I) = (COST(I) - SPVPE(I))/COST(I)
  194 CONTINUE
C
      WRITE(6,117) (R(M) ,M=1,10)
  117 FORMAT(1H0,*INTEREST RATES USED ARE*,18X,10F9.5)
      WRITE(6,118) (BC(M),  M=1,IR)
  118 FORMAT(1H ,*BENEFIT/COST RATIOS AT EACH DISCOUNT RATE*,10F9.3)
 1190 WRITE(6,119) NPROJ,NPROJ
  119 FORMAT(1H0,*PROJECT NUMBER IS *,I10,70X,I10,* IS PROJECT NUMBER.*)
      WRITE(6,1191)
 1191 FORMAT(1H ,*+++++------------------------------------------------
     1-----++ END OF PROJECT ++----------------------------------------
     2----+++++*)
```

```
  777 CONTINUE
      DO 24 M = 1,IR
      COST(M) = 0.0
      SPVLI(M) = 0.0
      SPVPE(M) = 0.0
      SANN(M)  = 0.0
   24 SVAL(M)  = 0.0
   21 NPROJ = ICON(1)
   22 IF(ICON(1).GT.9989999999) STOP
   23 IF(ICON(1).EQ. 0) STOP
      IF(IGARB.EQ.1)GO TO 15
      WRITE(6,140)
      WRITE(6,141)
      WRITE(6,142)
   25 GO TO 16
   26 STOP
      END
      SUBROUTINE VALREAD
      COMMON R(11),PV1(151,10),IR,PVFLO(10),ANN(10),PVPER(10),PVLIF(10),
     1SANN(10),SPVPE(10),SPVLI(10),VAL(151),NVAL,SVAL(10),NFLOW
     2 ,LIFE,LFLOW,ICON(20),ICONT,NPROJ
     3,PVCYC(10),ANCYC(10),PVANL(10),LCYCL
     4,PRICE,QUANT,AREA,CONST,SCALE,COST(10),BC(10)
     5,KEY,VL(8),IND(8)




C
      NC9 = 0
   44 NC = NC9 + 1
      NC9 = NC + 9
      READ(5,45) (VAL(N), N=NC,NC9)
   45 FORMAT(10F8.2)
C
C     READS CARDS UNTIL FIRST ELEMENT IS ZERO, THEN CHECKS WHETHER ALL
C     OF THIS LAST CARD IS BLANK.  IF SO, IT BACKS UP FROM FIRST
C     POSITION ON CARD TO FINAL NON-ZERO ELEMENT ON PRECEDING CARD.
C
      NI = NC9 -9
      NII = NI
   41 IF(VAL(NII)) 44,42,44
   42 NII = NII + 1
      IF(NII.LE.NC9) GO TO 41
   46 NI = NI - 1




C
C     THIS STATEMENT ASSURES THAT NI WILL NOT COUNT BELOW ZERO IN CASE
C     A BLANK CARD SHOWS UP WHERE DATA SHOULD BEGIN.
C     IF(NI.EQ,0) GO TO 47
      IF(VAL(NI)) 47,46,47
   47 NVAL = NI
      RETURN
      END
```

```
      SUBROUTINE VALRED2
      COMMON R(11),PV1(151,10),IR,PVFLO(10),ANN(10),PVPER(10),PVLIF(10),
     1SANN(10),SPVPE(10),SPVLI(10),VAL(151),NVAL,SVAL(10),NFLOW
     2 ,LIFE,LFLOW,ICON(20),ICONT,NPROJ
     3,PVCYC(10),ANCYC(10),PVANL(10),LCYCL
     4,PRICE,QUANT,AREA,CONST,SCALE,COST(10),BC(10)
     5,KEY,VL(8),IND(8)
      K = 0
      IFO = 0
      NTRPL = 10
      DO 10 I=1,151
   10 VAL(I) = 0.0
      NCNT = 0
   14 READ(5,15) (IND(I), VL(I), I = 1,8)
   15 FORMAT (8(I3,F7.2))
      DO 20 I = 1,8
      NCNT = IND(I)
   20 IF(NCNT.NE.0) VAL(NCNT) = VL(I)
      IF(NCNT.GT.0) GO TO 14
      IF(IND(1).EQ.0) GO TO 17
      ID = 0
    7 ID = ID + 1
      IF(IND(ID).NE.0.0) GO TO 7
      J = ID - 1
      NVAL = IND(J)
      GO TO 25
   17 I = 0
   16 I = I + 1
      K = 152 - I
      IF(VAL(K).EQ.0.0) GO TO 16
      NVAL = K
   25 CONTINUE
      IF(NVAL.EQ.1.AND.VAL(1).EQ.0.0) STOP
      IF(ICON(10).EQ.1) GO TO 71
      N = 0
   30 N = N + 1
      IF(VAL(N).EQ.0.0) GO TO 30
   31 NJ = N
      N = N + 1
      IF(N.GT.NVAL) GO TO 75
      IF(VAL(N).NE.0.0) GO TO 31
   32 N = N + 1
      IF(N.GT.NVAL) GO TO 75
      IF(VAL(N).EQ.0.0) GO TO 32
   33 NI = N
      NDIFF = NI - NJ
      NDIF1 = NDIFF - 1
      R2 = NDIFF
      IF(NTRPL.LT.20) NTRPL = NTRPL + 1
      IF(ICON(NTRPL).NE.0) IFO = ICON(NTRPL)
      IF(IFO.EQ.0) IFO = 1
      IF(IFO.GT.3) IFO = 1
   60 DO 70 I=1,NDIF1
      R1 = I
      K = NJ + I
      GO TO (61,62,63),IFO
   61 VAL(K) = R1 * (VAL(NI) - VAL(NJ))/R2 + VAL(NJ)
      IF(I.EQ.1) WRITE(6,161) NJ,NI
  161 FORMAT(1H ,*LINEAR INTERPOLATION USED FROM YEAR*,I4,*TO YEAR*,I4)
      GO TO 70
   62 VAL(K) = (SIN((R1/R2)*1.5707963268))*(VAL(NI) - VAL(NJ)) +VAL(NJ)
      IF(I.EQ.1) WRITE(6,162) NJ,NI
  162 FORMAT(1H ,*CONVEX INTERPOLATION USED FROM YEAR*,I4,*TO YEAR*,I4)
      GO TO 70
```

```
   63 VAL(K) = (1.0 - (COS((R1/R2)*1.5707963268)))*(VAL(NI) - VAL(NJ))
     1 + VAL(NJ)
      IF(I.EQ.1) WRITE(6,163) NJ,NI
  163 FORMAT(1H ,*CONCAVE INTERPOLATION USED FROM YEAR*,I4,*TO YEAR*,I4)
   70 CONTINUE
      N = NI
      GO TO 31
   75 CONTINUE
      IF(ICON(10).NE.9) GO TO 71
      DO 101 I = 1,NVAL
   99 WRITE(6,100) I,VAL(I)
  100 FORMAT(1H ,I3,3X,F15.7)
  101 CONTINUE
   71 CONTINUE
      RETURN
      END
      SUBROUTINE COMPUTE
      COMMON R(11),PV1(151,10),IR,PVFLO(10),ANN(10),PVPER(10),PVLIF(10),
     1SANN(10),SPVPE(10),SPVLI(10),VAL(151),NVAL,SVAL(10),NFLOW
     2 ,LIFE,LFLOW,ICON(20),ICONT,NPROJ
     3,PVCYC(10),ANCYC(10),PVANL(10),LCYCL
     4,PRICE,QUANT,AREA,CONST,SCALE,COST(10),BC(10)
     5,KEY,VL(8),IND(8)
C
      IF(ICON(2).NE.0) NFLOW = ICON(2)
C     COMPUTES VALUES, WRITES OUT, AND ACCUMULATES FOR TOTAL PROJECT
      KEY = ICON(6)
      IF(KEY.LT.2) KEY = 2


C
C         ROUTINE FOR COMPUTING CYCLICAL DATA BEGINS HERE AND ENDS AT 118
      LCYCL= NVAL - KEY + 1
      LIF1 = LIFE + 1
      DO 118 I = 1,IR
      CYCLE = 0.0
      PVFLO(I) = 0.0
      KE1Y = KEY-1
      IF(KEY.GT.NVAL) GO TO 120
      DO 104 J = 1,KE1Y
      PV = VAL(J)*PV1(J,I)
  104 PVFLO(I) = PVFLO(I) + PV
      DO 106 J = KEY,NVAL
      K = J+2-KEY
      PVE= VAL(J)*PV1(K,I)
  106 CYCLE = CYCLE + PVE
      PVCYC(I) = CYCLE *PV1(KE1Y,I)



C
C         FIND ANNUITY FOR LENGTH OF ONE CYCLE FROM PV OF ONE CYCLE.
      K = LCYCL + 1
      ANCYC(I) = ((R(I)-1.0)/(1.0-PV1(K,I)))*PVCYC(I)

C
C         FIND PV OF CYCLIC FLOWS FROM THE ANNUITY OF A CYCLE
      LIFCY = LIFE + 1 - KE1Y
      PVANL(I)= ((1.0-PV1(LIFCY,I))/(R(I)-1.0))*ANCYC(I)
      PVLIF(I) = PVFLO(I) + PVANL(I)
      LIF1 = LIFE + 1
      PVPER(I) = PVFLO(I) + (ANCYC(I)/(R(I) - 1.0))
  118 ANN(I) = PVLIF(I) * ((R(I)-1.0)/(1.0-PV1(LIF1,I)))
C
      GO TO 150
```

```
C         120 TO 133 CONTAINS ROUTINE FOR COMPUTING NON-CYCLICAL DATA.
  120 DO 124 I=1,IR
      PVFLO(I) = 0.0
      DO 124  J=1,NVAL
      PV=VAL(J)*PV1(J,I)
  124 PVFLO(I)=PVFLO(I)+PV
  130 DO 133 I=1,IR
  131 ANN(I) = PVFLO(I) * ((R(I)-1.0)/(1.0-PV1(LIF1,I)))
C      131 COMPUTES ANNUITY FOR LENGTH
  132 PVPER(I) = PVFLO(I)
  133 PVLIF(I) = PVFLO(I)
C

C         153 TO 157 WRITES OUT VALUES FOR EACH FLOW AND SUMS THEM
C         WITHIN EACH PROJECT,
  150 DO 157 I=1,IR
  151 K=I-1
  152 WRITE(6,153) NFLOW,R(I),PVFLO(I),PVLIF(I),PVPER(I), ANN(I),K,
     1VAL(I)
  153 FORMAT(1H ,I3,3X,F8.5,4F20.4,4X,I4,F20.4)
      IF(PVPER(1).LT.0.0) COST(I) = COST(I) + PVPER(I)
  154 SPVLI(I)=SPVLI(I)+PVLIF(I)
  155 SPVPE(I) = SPVPE(I) + PVPER(I)
  156 SANN(I)=SANN(I)+ANN(I)
  157 SVAL(I)=SVAL(I)+VAL(I)
      RETURN
      END

      SUBROUTINE PVARRAY
      COMMON R(11),PV1(151,10),IR,PVFLO(10),ANN(10),PVPER(10),PVLIF(10),
     1SANN(10),SPVPE(10),SPVLI(10),VAL(151),NVAL,SVAL(10),NFLOW
     2 ,LIFE,LFLOW,ICON(20),ICONT,NPROJ
     3,PVCYC(10),ANCYC(10),PVANL(10),LCYCL
     4,PRICE,QUANT,AREA,CONST,SCALE,COST(10),BC(10)
     5,KEY,VL(8),IND(8)
C
      WRITE(6,1)
    1 FORMAT(1H ,28X,*DAMID*,//,7X,*DISCOUNTING ANALYSIS MODEL FOR INVES
     1TMENT DECISIONS*,//,32X,*BY*,//,25X,*MICHAEL H. GIESKE*,//,
     231X,*AND*,//26X,*RONALD S. BOSTER*,//,1X,*ROCKY MOUNTAIN FOREST AN
     3D RANGE EXPERIMENT STATION*,//20X,*TUCSON, ARIZONA 1971*)
C         READS AND COUNTS DISCOUNT RATES (FROM HERE TO STATEMENT 15.)
      READ(5,7) (R(I),I=1,10)
    7 FORMAT(10F8.7)
      R(11) = 0.0
      IF(R(1)) 12,9,12
    9 WRITE(6,10)
   10 FORMAT(1H ,*ERROR IN INTEREST RATE INPUT------NO ENTRY FOR R(1)*)
   11 GO TO 31
   12 IR=0
   13 IR=IR+1
   14 IF(R(IR)) 13,15,13
   15 IR=IR-1
C
   16 DO 19 I=1,IR
   17 IF(R(I)-1.0) 18,19,19
   18 R(I)=R(I)+1.0
   19 CONTINUE
C         STATEMENTS 16 THROUGH 19 INSURE INTEREST RATES START WITH 1.0.
      DO 25 I=1,IR
      DO 25N=1,151
      L=N-1
   25 PV1(N,I) = 1.0/(R(I)**L)
   31 RETURN
      END
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U S D A FOREST SERVICE
RESEARCH NOTE RM - 201

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Blue Stain in Engelmann Spruce Trap Trees Treated with Cacodylic Acid

Thomas E. Hinds[1] and Paul E. Buffam[2]

One year after treatment, stain had penetrated the sapwood of untreated trees but was negligible in treated trees. Time of treatment had no effect upon the amount of stain in treatments acceptable for beetle control. The treatment that gave the best lethal effect on bark beetles also resulted in the least amount of blue stain. Incipient decay was present in the stained sapwood 1 year after treatment.

KEY WORDS: *Picea engelmannii, Leptographium engelmannii, Ceratocystis coerulescens, C. olivacea.*

The spruce beetle, Dendroctonus rufipennis irby), is the most serious pest of Engelmann ruce (Picea engelmannii Parry) forests in e United States. Because adult beetles prefer ndfalls and other downed material to live anding trees, live trees can be felled and used traps to attract the beetles. The trap tree ethod (Nagel et al. 1957) is an accepted man- ement practice in the suppression of this st.

The injection of the herbicide cacodylic d (diamethylarsenic acid) into living spruce cently has been shown to be a practical ethod for producing trap trees lethal to the spruce beetle (Buffam 1971, Buffam and Yasinski 1971, Frye and Wygant 1971). The infested trap trees need not be logged, burned, or treated with chemicals to kill the resultant brood. The trap trees can be safely harvested any time after the flight period of the beetle, or left in the woods.

With an extended period of time available for harvesting lethal trap trees, the question arises concerning the deterioration of these trees. A study of the deterioration of beetle-killed spruce in Colorado (Hinds et al. 1965) revealed that trees on the ground begin to decay rapidly, and that the average amount of decay varied from 16-19 percent within 5 years, depending upon the proportion of the tree in contact with the ground. The sapwood of infested Engelmann spruce is soon invaded by blue stain fungi carried by the spruce beetle, and the entire sapwood is normally colonized within 1 or 2 years.

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Frye and Wygant (1971) observed that blue stain was suppressed in trap trees treated with cacodylic acid and felled. This study was made to determine the effect of cacodylic acid upon decay and blue stain development in Engelmann spruce trap trees. It was made in conjunction with a study by Buffam (1971) to determine the best methods of producing lethal trap trees.

Methods

Two study areas were chosen in May 1969, adjacent to a spruce beetle-infested stand on the Santa Fe National Forest, south of Coyote, New Mexico. Four treatment blocks were designated in each area. In each block, 21 mature spruce trees were numbered for identification. The following treatments were made to three trees in each of the eight blocks:[3]

1. Frilled and treated with full-strength Silvisar 510 and left standing.
2. Frilled and treated with full strength Silvisar 510 and felled.
3. Frilled and treated with half-strength Silvisar 510 and left standing.
4. Frilled and treated with half-strength Silvisar 510 and felled.
5. Frilled only and left standing (control).
6. Frilled only and felled (control).
7. Felled without frilling or treating (control).

All frills penetrated the sapwood and were chopped with a hatchet. Silvisar 510 was applied to the frills with a plastic squeeze bottle. Full-strength Silvisar 510 was diluted with an equal quantity of tap water for the half-strength treatments. About 1 ml of solution was applied per inch of tree circumference.

The four blocks in each area were treated at different times. These times—based on July 15 as peak beetle flight—were:

A. Frilled and treated 8 weeks before peak beetle flight (May 21) and felled 4 weeks before peak flight (June 17).
B. Frilled and treated 8 weeks before peak beetle flight (May 21) and felled 2 weeks before peak flight (June 30).
C. Frilled and treated 4 weeks before peak beetle flight (June 16) and felled 2 weeks before peak flight (June 30).
D. Frilled and treated 4 weeks before peak beetle flight (June 16) and felled later the same week (June 18).

Treatments were assigned at random. In total, 168 trees—24 within each of seven treatment categories—were involved in the test. The trees averaged from 15 to 17 inches d.b.h., 80 to 90 feet in height, and were 100 to 207 years old (Buffam 1971). Volume of the six trees in each treatment-time combination ranged from 320-510 cubic feet.

The results were evaluated during the period June 9-24, 1970. Trees left standing in 1969 were felled, and all test trees were limbed and bucked into log lengths of 8 to 24 feet to a 6-inch top. Logs and blue stain were measured so that cubic-foot volumes could be computed by use of Smalian's formula. Where blue stain did not extend throughout the length of a log additional cuts were made to determine its length. At least one sample of blue stain was taken from each tree for isolation of fungi.

Results

There were no significant differences between similar treatments in the two areas, so data from both areas were combined for analysis. The data (table 1) were analyzed as a factorial experiment to determine the main effects and interactions between treatment and treatment times on blue stain. Three main conclusions emerged from the analysis:

1. Treatment time had no effect on blue stain with the exception of treatment D.
2. The effect of acid strength was different for standing trees (which sustained few beetle attacks and negligible amounts of blue stain) and down trees (in which blue stain decreased with increased dosage).
3. There was no interaction between treatment time and dosage.

A total of 256 isolations were made from stained sapwood: 224 from blue stain and 32 from brown stain associated with ambrosia beetle galleries. More than one fungus was commonly isolated from a specimen. Leptographium engelmannii Davidson was the most common blue stain fungus; it was isolated from 95 percent of the blue stain samples. In addition to L. engelmanni, Ceratocystis olivacea (Mathiesen) Hunt was isolated from blue stain in 12 trees and C. coerulescens (Münch) Bakshi from seven trees. The fungus most consistently associated with the small pockets of brown stain around the ambrosia beetle galleries was C. coerulescens; it was isolated from 80 percent of the brown stain samples.

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[3] *Trade names are used for the benefit of the reader and do not imply endorsement by the U. S. Department of Agriculture. Silvisar 510 (manufactured by the Ansul Company) contains the equivalent of 6.0 lb. of cacodylic acid/gal. Silvisar 510 Tree Killer has been approved by the Pesticides Regulation Division of the Environmental Protection Agency (February 24, 1971) for use in bark beetle control by professional foresters in the Rocky Mountains of South Dakota, Colorado, Arizona, and New Mexico.*

Table 1.--Percent blue stain volume by treatment and treatment time (1969) in Engelmann spruce trap trees. Each figure is an average of six trees.

No.	Treatment Description	Treated May 21[1] Felled June 17 (A)	Treated May 21[1] Felled June 30 (B)	Treated June 16[1] Felled June 30 (C)	Treated June 16[1] Felled June 18 (D)
1.	Frill, acid full strength, standing	0.6	2.7	2.5	2.6
2.	Frill, acid full strength, felled	2.3	5.0	1.6	11.2
3.	Frill, acid half strength, standing	1.5	3.5	3.1	3.5
4.	Frill, acid half strength, felled	5.1	4.7	2.9	20.9
5.	Frill, no acid, standing[2]	0.0	0.0	0.2	0.3
6.	Frill, no acid, felled	28.5	27.7	36.8	28.1
7.	Felled only	17.2	33.0	24.0	28.1

[1] Note that treatments 1, 3, and 5 did not involve felling.

[2] Trees in this treatment attracted very few beetles and were still alive in 1970.

L. engelmanni was also isolated five times. An unidentified species of Ceratocystis and three Graphium spp. were also isolated from stain.

Advance sap rot was not evident in any of the trap trees. Although the felled trees had been on the ground approximately 1 year, the only evidence of sap rot fungi was from the isolations. Fomes pinicola (Swartz) Cke. was isolated 24 times from stain samples from felled trees. Two other unidentified sap rot organisms were isolated from eight samples. The isolations indicated that incipient decay was present in the down trees, and that early removal of trap trees is necessary to obtain maximum lumber values.

Discussion

Frye and Wygant's (1971) observations that blue stain was inhibited in Engelmann spruce trap trees treated with cacodylic acid was substantiated in this study. Although blue stain is of secondary importance compared to the reduction of beetle populations, less degrade by blue stain would be a plus factor in evaluating the method for producing lethal trap trees.

Treatments 1, 3, and 5, frilled but left standing, were ineffective as trap trees because very few beetles were attracted to them (Buffam 1971). All 24 trees in treatment 5 were still alive 12 and 13 months after being frilled in 1969. Treatments 6 and 7 (no acid, felled) were controls, and should not be considered in an analysis of treatments. While these trap trees readily attracted insects, they would have to be treated or disposed of prior to beetle emergence. Even though differences between full- and half-strength acid in treatments 2 and 4 on blue stain were significant, the small amount of blue stain volume involved may not be worth the added cost of the full-strength treatment. Here the choice of treatment would best be made upon the difference in lethal effect upon the beetles. Since there was no difference in the lethal effect between the two treatments (Buffam 1971), treatment 4 with half-strength acid would be preferable.

Significantly more live brood was found in timing treatment D, probably because time between treatment and felling was not long enough for adequate acid translocation. Otherwise there was no effect between treatment time and amount of blue stain. Late snow cover in the Rocky Mountains would probably eliminate timing treatments A and B.

Buffam (1971) recommended a lethal trap method in which trees are frilled and treated with half-strength Silvisar 510 approximately 4 weeks before peak beetle flight and felled approximately 2 weeks before peak beetle flight (June 16 and June 30, 1969 in this study). This method, treatment 4-C, would also result in only small amounts of blue stain.

Blue stain in trap trees not treated with acid was typical of that found in beetle-killed trees. Stain completely penetrated the sapwood within a year. Stain in acid-treated trees was usually in small streaks 2 to 6 inches wide which extended upward from the butt varying distances, but only in areas where the tree was in contact with the ground. Rarely did the stain encompass the sapwood circumference, and then only in the basal portion of the tree below the frill.

Damage to the sapwood by ambrosia beetles was common in some trees. Ambrosia beetles are important because their galleries penetrate the sapwood and reduce the grade of the lumber cut from the logs. Frye and Wygant (1971) found that acid treatment did not affect construction of egg galleries by <u>Trypodendron lineatum</u> or kill the parent adults, and our limited data confirm this. Beetle damage was heavy in trees in treatments 1 and 3 in which there was little blue stain, whereas damage was negligible in the treatments 6 and 7 where blue stain was more common. It appeared that ambrosia beetles did not attack blue stained sapwood.

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U S D A FOREST SERVICE
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Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Elk and Deer Use are Related to Food Sources in Arizona Ponderosa Pine

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Elk use within ponderosa pine stands was higher on those areas with higher herbage yields, lower timber basal areas, and some alligator juniper. Long-term deer use appeared to be essentially random.

KEY WORDS: Deer, elk, *Pinus ponderosa*, wildlife management.

The local distribution of elk and mule deer s of widespread interest to sportsmen, sight-eers, and land managers. Knowledge of the ype of areas game animals tend to frequent makes the animals easier to find, and analysis of the frequented areas gives land managers nsight into habitat preferences that can improve management practices.

Considerable work has been done in the ast decade on relating big-game use to forest openings and to timber harvesting in southwestern conifer forests (Reynolds 1969; Pearson 968; Patton 1969). Openings in ponderosa pine (*Pinus ponderosa*) forests improve the habitat for both elk and deer, although deer are reluctant to move far from the forest edge. Reduction of timber density through logging or thinning encourages the growth of herbaceous plants. This additional forage is often attractive to elk and deer. Slash cleanup after timber cutting may not affect elk use, but may be detrimental to deer use.

Lay (1969) and Zeedyk (1969) have suggested that, on forested game range, forage diversity is often the key to habitat quality. Work with field preferences of tame deer has indicated that forbs are the most important summer range forage class on the Beaver Creek watershed in Arizona (Neff 1969).

Topography seems to have little direct influence on the distribution of southwestern elk and deer populations. Most of the differences in game animal use relative to topography have been associated with vegetation differences (Patton 1969; Reynolds 1962, 1964).

This Note summarizes observations during 1961-69 on the distribution of elk and deer pellet groups in relation to environmental factors within ponderosa pine stands. No attempt was made to measure or analyze game use in relation to natural or artificial openings, since this has been done elsewhere.

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Methods and Study Area

Data were collected on clusters of plots, each cluster containing five herbage production plots and timber inventory points, and four pellet group plots. Herbage production was determined by species on 9.6-square-foot plots by the weight estimate method (Pechanec and Pickford 1937) during 3 years of the study. Timber variables were described by the Ffolliott and Worley (1965) system. Physiographic characteristics recorded included soils, elevation, aspect, slope position, and slope steepness. The pellet groups were counted on 1/100-acre plots in 63 clusters.

The pellet groups were initially cleared from the plots in 1960, then counted and cleared annually until 1964.[2] The accumulated groups were counted in 1969.

A t-test was used to compare total pellet group counts between clusters for those environmental factors which were either present or absent. Variables so tested included presence of Gambel oak (Quercus gambelii) with high acorn potential,[3] dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum), alligator juniper (Juniperus deppeana), and differences among soils.

Regression was used to analyze the association between pellet group counts and those variables which are essentially always present, but in varying amounts. Variables tested by regression were grass production, forb production, total herbage production, browse production, ponderosa pine basal area, ponderosa pine site index, elevation, aspect, slope position, and slope percent.

The data were collected in the ponderosa pine type on the Beaver Creek watershed, approximately 40 miles south of Flagstaff, Arizona. Elevations range from 6,600 to 7,400 feet. The soils are volcanics with considerable surface rockiness. Herbage yields averaged 208 pounds per acre, and browse yields 22 pounds per acre. The timber composition is about 85 percent ponderosa pine and 15 percent associated woodland species such as Gambel oak and alligator juniper. The timber averaged 110 square feet of basal area per acre with a range from 30 to 180 square feet on individual clusters.

Elk and deer densities were low during th study period, probably less than two animal each per square mile; pellet groups per acr per month averaged 0.85 for elk and 0.74 fo deer (calculated from Wallmo 1964; Neff 1970)

Results and Discussion

Because the distribution of elk use as indexed by pellet group counts was rather consistent from year to year, significant association were apparent between total pellet group count and certain site characteristics. Elk use wa directly related to total herbage productio (fig. 1) and to forb production, which is consistent with the grazing habits of this big gam species. Elk use was also inversely relate to ponderosa pine basal area. This may represent a combination of a preference for lowe forest densities[4] and of greater forage availability, since more herbage is produced wher the tree density is lower.

Elk use was significantly higher on ponderosa pine sites where alligator juniper wa also present. The total pellet group coun averaged 5.44 on clusters with alligator junipe and 2.80 on those without alligator juniper This may be a direct food preference—junipe fruit and foliage are at times a major item i the elk diet (U.S. Forest Service 1967); or a indirect food preference—herbage productio is an average of 65 percent higher (272 versu 165 pounds per acre) on sites with alligato juniper. Elk use of areas with juniper mixed with ponderosa pine could also be a cove preference (Packard and Anderson 1969).

The distribution of deer pellet groups for the entire period of study was rather diffuse and appeared to be essentially random. Within shorter time periods, however, deer seemed to prefer certain types of sites over others. For instance, deer pellet group counts were significantly greater on clusters with acorn-producing Gambel oak in 1961, when a massive crop of acorns was produced. In other years, clusters with dwarf mistletoe or alligator juniper received significantly more deer use than clusters without them. Although there was insufficient sampling to document the annual trends precisely, the results suggest that deer

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[2] *We acknowledge the assistance rendered by Peter F. Ffolliott, formerly Associate Silviculturist, Rocky Mountain Forest and Range Experiment Station, and by personnel of the Arizona Game and Fish Department.*

[3] *Eight to sixteen inches d.b.h. without crown dieback.*

[4] *Personal communication with H. G. Reynolds, Project Leader, Wildlife Habitat Research, Forest Hydrology Laboratory, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.*

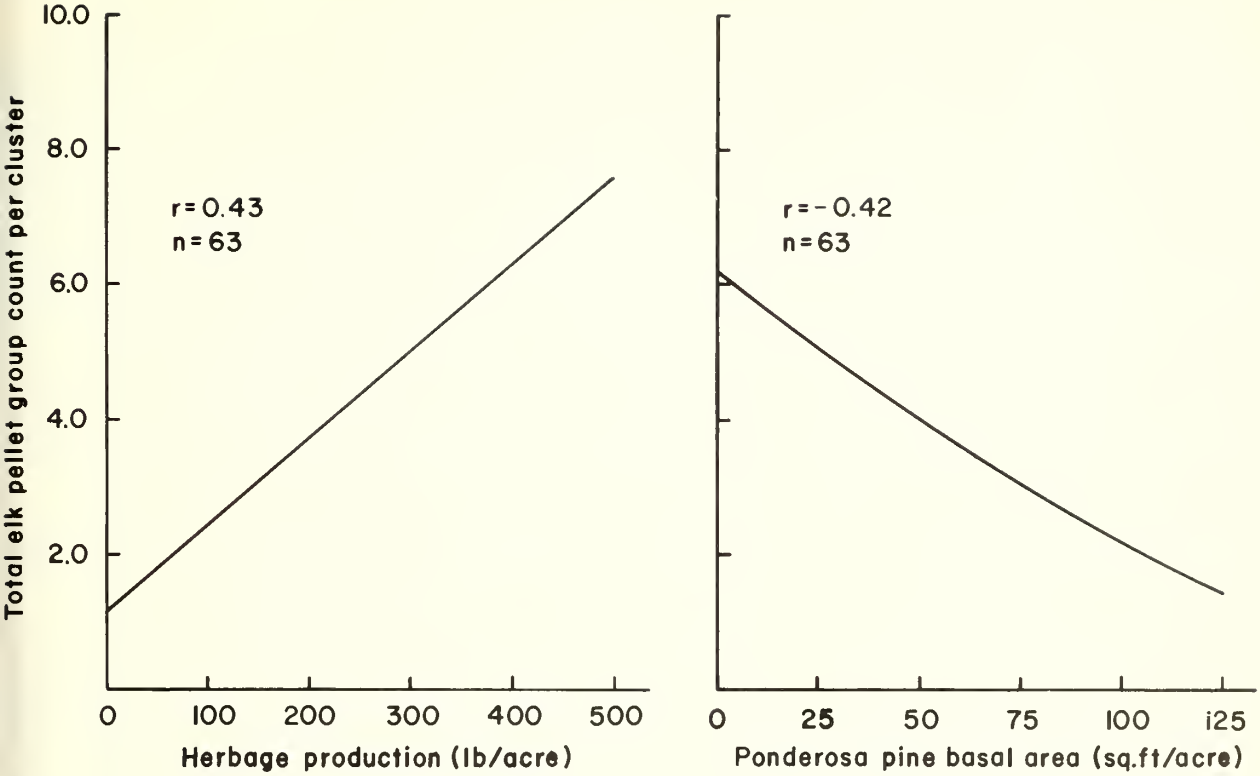

Figure 1.--Relationships of total elk pellet group counts to herbage production and ponderosa pine basal area.

preferences or requirements may vary from year to year, a fact which may not be apparent in long-term pellet group accumulations.

Neither elk nor deer use was significantly related to ponderosa pine site index, browse production, soils, or topography. Likewise, no significant relationships were found between deer use and herbage variables or ponderosa pine basal area, or between elk use and presence of acorn-yielding Gambel oak, dwarf mistletoe, or grass production.

The association of pellet groups with habitat factors does not in itself constitute proof of cause and effect, but it does indicate animal habitat preference. Therefore, management to maintain or improve combined elk and deer habitat in areas similar to Beaver Creek might include maintaining Gambel oak and alligator juniper, where possible, as components of the ponderosa pine vegetation type. Thinning high-density forest stands, maintenance of natural forest openings, and seeding areas of soil disturbance with plants palatable to game species as suggested by Reynolds (1969) should also improve the summer elk and deer forage supply.

Summary

Counts of elk and deer pellet groups were related to vegetation and other site characteristics within ponderosa pine stands for the period 1961-69. Only vegetation characteristics were found to relate significantly to game use. Specific results were:

1. Relatively consistent elk use patterns showed long-term preferences for the areas within ponderosa pine stands with higher herbage yields, lower timber basal area levels, and some alligator juniper.
2. Deer use patterns appeared to be essentially random; no long-term preference was noted for any site characteristics measured.

For areas similar to Beaver Creek, elk and deer may benefit by (a) maintaining Gambel oak and alligator juniper as components of the ponderosa pine vegetation type, (b) thinning high-density forest stands and maintaining natural forest openings to benefit the native herbaceous forage supply, and (c) seeding disturbed areas to forage species palatable to big game.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-203

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DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

A Computer Program for Computing Streamflow Volumes

Paul A. Ingebo, Wilson B. Casner,[1] and Gary L. Godsey[2]

Computations are based on tabulations of gage heights prepared from continuous stream-gage records. Any of several formulas or rating tables may be selected for each water year's computations. Elements of flow show in a sequence printout of daily volumes. An annual volume summary, tabulated by day and month, may be printed in one or more different units.

KEY WORDS: Stream gaging, programing (computers).

The Rocky Mountain Forest and Range Experiment Station maintains many experimental watersheds where gage heights from streamflow are continuously recorded. A computer program has been designed to reduce and compile volumes from gage height tabulations based on these records. The program has built-in flexibility to: (1) process data from more han one gage or water year during any one computer run, (2) compute volumes by either of two methods, one using an algebraically derived integrating equation, the other an average of the beginning and ending rate of flow, for each interval, and (3) print a summary of daily volumes of streamflow in any one of several units of measure. The program also selects and prints out the three highest recorded peak flows on different days for two seasons of the year on each station summary. In addition, it checks for many of the more common errors experienced in compiling data, and summarizes those detected in an error listing.

Development and Description of Program

Stream gages operated for experimental purposes by the Experimental Station in Arizona have fixed artificial controls; most are either V-notch weirs or flumes. Ratings for these gages are either in table form or formula. Formulas are of the type $Q = C H^D$, where Q is the instantaneous rate of flow in c.f.s., H is head or gage height in feet, C and D are gage station constants. Rating tables contain instantaneous rate of flow over the expected range in heads.

As initially developed, an individual data reduction program was written for each rating formula. These programs followed the mathematical procedures used for past "hand" computations, and output was restricted to one unit of measure, usually cubic feet. During subsequent trials it was found that, with the computer, data could be reduced by an integrating method for those stations with a single

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[2] *Computer Programer, formerly at Rocky Mountain Forest and Range Experiment Station, Fort Collins; now affiliated with Control Data Corporation, Minneapolis, Minnesota.*

formula rating, in place of the averaging method first used with "hand" computations. At about the same time, demands were building up for programs that use rating tables in the reduction of data, that produce output in more than one unit of measure, and detect and pinpoint those errors commonly made in compiling streamflow data. To meet these demands and permit more efficient and continuous computer runs with data from different gaging stations, later revisions combined these desired options in one program.

During initial development, the program was modified and run on a variety of different computers. It has been updated through the addition of certain data checks and edits, and is presently being run on the Control Data Corporation 6400 at Arizona State University, Tempe.[3] The program is written in FORTRAN IV. Streamflow volumes can be computed and summarized by any one of several rating formulas or tables. Head values up to 9.999 feet can be used with a 90° or 120° V-notch weir formula, and up to 4.000 feet with a rating table if the flow rates do not exceed the limit set in the rating table format. Limits are based on locally estimated streamflow volumes and, thus, represent maximum tested values which in other instances could possibly be exceeded. A program run may contain several stations and several water years (October 1 - September 30).

Input

The 80-column punch card, adopted as standard input to the computer, permits maximum flexibility in program development and handling of data. Card input consists of nine classes of information loaded in the following order:

1. Program deck
2. Rating table data
3. Station identification card
4. Summary station descriptions
5. Streamflow data
6. Remarks code card (optional)
7. Remarks cards (optional)
8. Trailer card
9. End-of-run card

Formats for the input cards are given in table 1. Rating table cards are punched with eight entries to a card. The computer accepts the first entry for a rating table as the c.f.s. flow rate for the 0.010-foot gage height or head value, and each succeeding table entry is taken to be for a 0.010-foot higher gage height. The station identification card contains information needed in processing individual water year records. The summary cards carry descriptive information about the watershed and the gaging station. This information can be in alphanumeric form, and is contained on three cards which are always included, even if all three are left blank.

For maximum flexibility in assembling streamflow data, only one gage height with supplemental information is punched per card. Entries in card columns 29 and 61 are not needed for computation of volumes, but are carried forward as an aid in interpretation of output data.

The remarks code card and remarks cards are added after the streamflow data cards whenever it is desired to supplement information on the summary for a particular station year. A remarks code card must always precede the remarks card(s).

The trailer card is used to separate data sets and to indicate the unit to be used in the output summary. The end-of-run card signals end of input and that no new station data follow.

Output

Output from the program is printed "on line" (figs. 1 and 2). Figure 1 includes (1) the streamflow input data, (2) duration of interval, (3) instantaneous rate of flow for each gage height, (4) flow volume for each interval, (5) cumulative flow in cubic feet within each day, (6) cumulative flow in acre-feet within each day, (7) average rate of flow for the interval, and (8) the average rate of flow for the day in c.f.s. Printout of zero volumes on days of no flow is suppressed on the daily sheet (fig. 1) to conserve computer running time. Statements indicating duration of suppressed "no flows" are printed to maintain a continuous record.

Figure 2 illustrates a station summary of one water year. Line 1 duplicates the information given on the station identification card. Printed lines 2, 3, and 8 describe the station as keypunched in summary cards 1, 2, and 3. Additional remarks from the remarks cards are printed out on the summary just above the tabulation of daily streamflows.

During computations the peak instantaneous flow, Q[I], determined by gage heights, is stored for each day. From these, the three highest instantaneous peak flows for each of two seasons of the year (October-May and June-September) are recorded in descending order on printed

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[3] *Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

Table 1.--Card Formats

Card Name	Columns	Description
Rating Table	1-10	Flow rate - c.f.s. (XXXXX.XXXXX)[1]
	11-20	Flow rate - c.f.s.
	21-30	Flow rate - c.f.s.
	31-40	Flow rate - c.f.s.
	41-50	Flow rate - c.f.s.
	51-60	Flow rate - c.f.s.
	61-70	Flow rate - c.f.s.
	71-80	Flow rate - c.f.s.
Station Identification	1-40	Station, general location (Alphanumeric)
	41-42	Station number
	43-44	Blank
	45-48	Gage limit in feet (X.XXX)[1]
	49-50	Blank
	51-62	120 DEG V, 90 DEG V, or RATING TABLE
	63-64	Blank
	65-70	Watershed area in acres (XXXX.XX)[1]
Summary Cards 1 and 2	1-160	Alphanumeric information on watershed
Summary Card 3	161-240	Alphanumeric information on gage
Data	1-2	Gaging station identification number
	4-5	Month
	7-8	Day
	10-11	Year
	13-16	Time of gage height reading (military)
	23-26	Gage height in feet (X.XXX)[1]
	29	A number 1 when time or head is estimated
	61	A number 1 when water enters the pond during day but in amounts too small to cause flow through the weir.
Remarks Code	1-2	Blank
	3	Letter R
	4-5	A number indicating how many 6-column fields (10 per card) are to be read from the remarks cards following this one.
Remarks	1-60	Alphanumeric information to be printed after word 'REMARKS' on the station summary. The number of remarks cards should not exceed 6.
Trailer	1-4	Blank
	5	1, 2, 3, or 4 to obtain a station summary in cubic feet, acre feet, cubic feet per second, or area inches.
End of Run	1	0-7-8
	2	0-7-8
	3-8	E.O.F.

[1] Decimal point is not keypunched.

```
RMFREST1 WHITESPAP A NEAR PRESCOTT, APIZ   1  1.000  120 OEG V      302.890

 SO MO DA YR  TIME    D.T.    GAGE HT.      Q(I)         Q(INT)          Q(TOT)        Q(TOT)         AVG. FLOW
             (MIL)   (SEC)     (FT)        (CFS)        (CU FT)         (CU FT)      (ACRE FT)         (CFS)

  1 10  1 68     0       0    0.000       0.00000      0.0000000       0.0000000      0.000000        0.00000

  FROM     10/  1     TO    10/  2    THERE WAS NO FLOW RECOROED

  1 10  3 68  2400   86400    0.000 WIP   0.00000      0.0000000       0.0000000      0.000000        0.00000

  1 10  4 68  2400   86400    0.000       0.00000      0.0000000       0.0000000      0.000000        0.00000

  FROM     10/  5     TO     1/  2    THERE WAS NO FLOW RECORDEO

  1  1  3 69  2400   86400    0.000 WIP   0.00000      0.0000000       0.0000000      0.000000        0.00000

  1  1  4 69  2400   86400    0.000 WIP   0.00000      0.0000000       0.0000000      0.000000        0.00000

  1  1  5 69  2400   86400    0.000 WIP   0.00000      0.0000000       0.0000000      0.000000        0.00000

  1  1  6 69  1230   45000    0.000       0.00000      0.0000000       0.0000000      0.000000        0.00000
  1  1  6 69  1231      60     .001        .00000       .0000035        .0000035       .000000         .00000
  1  1  6 69  1300    1740     .010        .00006       .0313952        .0313986       .000001         .00002
  1  1  6 69  1425    5100     .035        .00120      2.4604873       2.4918859       .000057         .00048
  1  1  6 69  2400   34500     .035        .00120     41.5571219      44.0490078       .001011         .00120
                                                                               RATE OF FLOW IS      .0005098 CFS

  1  1  7 69   600   21600     .038        .00147     28.8633193      28.8633193       .000663         .00134
  1  1  7 69   840    9600     .041        .00177     15.5636512      44.4269705       .001020         .00162
  1  1  7 69  1100    8400     .034        .00112     12.0425125      56.4694830       .001296         .00143
  1  1  7 69  1500   14400     .037        .00138     17.9776857      74.4471687       .001709         .00125
  1  1  7 69  2400   32400     .033        .00104     39.1029253     113.5500940       .002607         .00121
                                                                               RATE OF FLOW IS      .0013142 CFS

  1  1  8 69   600   21600     .035        .00120     24.2477519      24.2477519       .000557         .00112
  1  1  8 69   800    7200     .043        .00199     11.3748767      35.6226286       .000818         .00158
  1  1  8 69   845    2700     .034        .00112      4.1405231      39.7631517       .000913         .00153
  1  1  8 69  2400   54900     .033        .00104     59.4111581      99.1743098       .002277         .00108
                                                                               RATE OF FLOW IS      .0011479 CFS

  1  1  9 69  2400   86400     .031        .00089     83.6142938      83.6142938       .001920         .00097
                                                                               RATE OF FLOW IS      .0009678 CFS

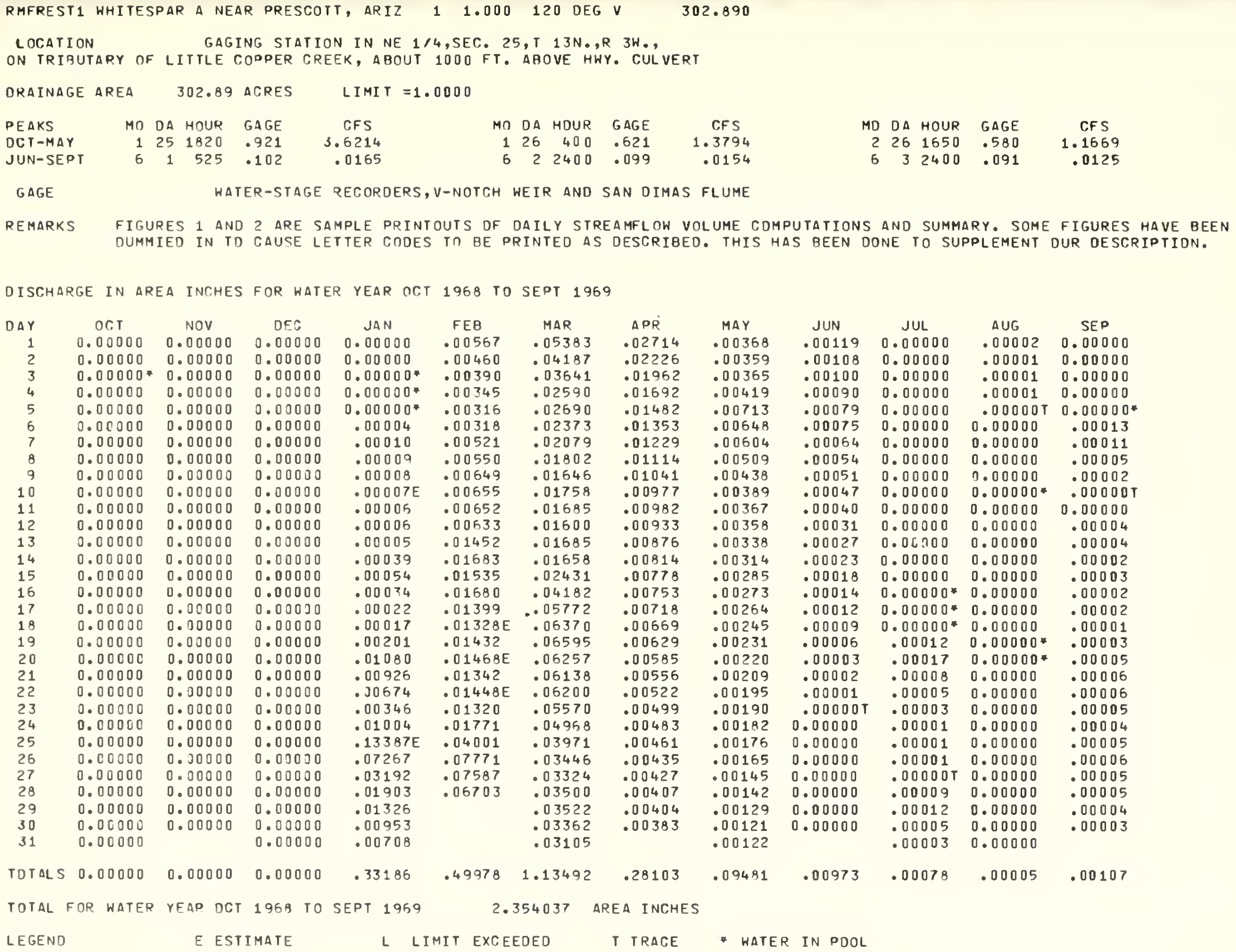
  1  1 10 69  2400   86400     .030 EST    .00083     74.3082097      74.3082097       .001706         .00086
                                                                               RATE OF FLOW IS      .0008600 CFS

  1  1 11 69  2400   86400     .028        .00070     65.7106058      65.7106058       .001509         .00076
                                                                               RATE OF FLOW IS      .0007605 CFS

  1  1 12 69   600   21600     .029        .00076     15.7344508      15.7344508       .000361         .00073
  1  1 12 69   800    7200     .042        .00188      9.1573290      24.8917799       .000571         .00127
  1  1 12 69   850    3000     .041        .00177      5.4848159      30.3765957       .000697         .00183
  1  1 12 69   920    1800     .030        .00083      2.2766993      32.6532950       .000750         .00126
  1  1 12 69  1041    4860     .028        .00070      3.6962216      36.3495166       .000834         .00076
  1  1 12 69  2400   47940     .026        .00058     30.6100336      66.9595502       .001537         .00064
                                                                               RATE OF FLOW IS      .0007750 CFS

  1  1 13 69  2400   86400     .028        .00070     55.1670192      55.1670192       .001266         .00064
                                                                               PATE OF FLOW IS      .0006385 CFS
```

Figure 1.--Computer printout of daily streamflow volumes where days of no flow are suppressed (not tabulated).



```
RMFREST1 WHITESPAR A NEAR PRESCOTT, ARIZ   1  1.000  120 DEG V       302.890

 LOCATION            GAGING STATION IN NE 1/4,SEC. 25,T 13N.,R 3W.,
ON TRIBUTARY OF LITTLE COPPER CREEK, ABOUT 1000 FT. ABOVE HWY. CULVERT

DRAINAGE AREA     302.89 ACRES      LIMIT =1.0000

PEAKS          MO DA HOUR  GAGE       CFS              MO DA HOUR  GAGE       CFS              MO DA HOUR  GAGE       CFS
OCT-MAY         1 25 1820  .921     3.6214              1 26  400  .621    1.3794               2 26 1650  .580    1.1669
JUN-SEPT        6  1  525  .102      .0165              6  2 2400  .099     .0154               6  3 2400  .091     .0125

 GAGE               WATER-STAGE RECORDERS,V-NOTCH WEIR AND SAN DIMAS FLUME

REMARKS     FIGURES 1 AND 2 ARE SAMPLE PRINTOUTS OF DAILY STREAMFLOW VOLUME COMPUTATIONS AND SUMMARY. SOME FIGURES HAVE BEEN
            DUMMIED IN TO CAUSE LETTER CODES TO BE PRINTED AS DESCRIBED. THIS HAS BEEN DONE TO SUPPLEMENT OUR DESCRIPTION.


DISCHARGE IN AREA INCHES FOR WATER YEAR OCT 1968 TO SEPT 1969

DAY        OCT       NOV       DEC       JAN       FEB       MAR       APR       MAY       JUN       JUL       AUG       SEP
  1     0.00000   0.00000   0.00000   0.00000    .00567    .05383    .02714    .00368    .00119  0.00000    .00002  0.00000
  2     0.00000   0.00000   0.00000   0.00000    .00460    .04187    .02226    .00359    .00108  0.00000    .00001  0.00000
  3     0.00000*  0.00000   0.00000   0.00000*   .00390    .03641    .01962    .00365    .00100  0.00000    .00001  0.00000
  4     0.00000   0.00000   0.00000   0.00000*   .00345    .02590    .01692    .00419    .00090  0.00000    .00001  0.00000
  5     0.00000   0.00000   0.00000   0.00000*   .00316    .02690    .01482    .00713    .00079  0.00000    .00000T 0.00000*
  6     0.00000   0.00000   0.00000    .00004    .00318    .02373    .01353    .00648    .00075  0.00000  0.00000    .00013
  7     0.00000   0.00000   0.00000    .00010    .00521    .02079    .01229    .00604    .00064  0.00000  0.00000    .00011
  8     0.00000   0.00000   0.00000    .00009    .00550    .01802    .01114    .00509    .00054  0.00000  0.00000    .00005
  9     0.00000   0.00000   0.00000    .00008    .00649    .01646    .01041    .00438    .00051  0.00000  0.00000    .00002
 10     0.00000   0.00000   0.00000    .00007E   .00655    .01758    .00977    .00389    .00047  0.00000  0.00000*   .00000T
 11     0.00000   0.00000   0.00000    .00006    .00652    .01685    .00982    .00367    .00040  0.00000  0.00000  0.00000
 12     0.00000   0.00000   0.00000    .00006    .00633    .01600    .00933    .00358    .00031  0.00000  0.00000    .00004
 13     0.00000   0.00000   0.00000    .00005    .01452    .01685    .00876    .00338    .00027  0.00000  0.00000    .00004
 14     0.00000   0.00000   0.00000    .00039    .01683    .01658    .00814    .00314    .00023  0.00000  0.00000    .00002
 15     0.00000   0.00000   0.00000    .00054    .01535    .02431    .00778    .00285    .00018  0.00000  0.00000    .00003
 16     0.00000   0.00000   0.00000    .00034    .01680    .04182    .00753    .00273    .00014  0.00000* 0.00000    .00002
 17     0.00000   0.00000   0.00000    .00022    .01399    .05772    .00718    .00264    .00012  0.00000* 0.00000    .00002
 18     0.00000   0.00000   0.00000    .00017    .01328E   .06370    .00669    .00245    .00009  0.00000* 0.00000    .00001
 19     0.00000   0.00000   0.00000    .00201    .01432    .06595    .00629    .00231    .00006    .00012  0.00000*   .00003
 20     0.00000   0.00000   0.00000    .01080    .01468E   .06257    .00585    .00220    .00003    .00017  0.00000*   .00005
 21     0.00000   0.00000   0.00000    .00926    .01342    .06138    .00556    .00209    .00002    .00008  0.00000    .00006
 22     0.00000   0.00000   0.00000    .00674    .01448E   .06200    .00522    .00195    .00001    .00005  0.00000    .00006
 23     0.00000   0.00000   0.00000    .00346    .01320    .05570    .00499    .00190    .00000T   .00003  0.00000    .00005
 24     0.00000   0.00000   0.00000    .01004    .01771    .04968    .00483    .00182  0.00000    .00001  0.00000    .00004
 25     0.00000   0.00000   0.00000    .13387E   .04001    .03971    .00461    .00176  0.00000    .00001  0.00000    .00005
 26     0.00000   0.00000   0.00000    .07267    .07771    .03446    .00435    .00165  0.00000    .00001  0.00000    .00006
 27     0.00000   0.00000   0.00000    .03192    .07587    .03324    .00427    .00145  0.00000    .00000T 0.00000    .00005
 28     0.00000   0.00000   0.00000    .01903    .06703    .03500    .00407    .00142  0.00000    .00009  0.00000    .00005
 29     0.00000   0.00000   0.00000    .01326              .03522    .00404    .00129  0.00000    .00012  0.00000    .00004
 30     0.00000   0.00000   0.00000    .00953              .03362    .00383    .00121  0.00000    .00005  0.00000    .00003
 31     0.00000             0.00000    .00708              .03105              .00122              .00003  0.00000

TOTALS 0.00000   0.00000   0.00000    .33186    .49978   1.13492    .28103    .09481    .00973    .00078    .00005    .00107

TOTAL FOR WATER YEAR OCT 1968 TO SEPT 1969        2.354037  AREA INCHES

LEGEND              E ESTIMATE          L  LIMIT EXCEEDED       T TRACE     * WATER IN POOL
```

Figure 2.--Annual summary of streamflow with daily discharge given in area-inches.

lines 6 and 7. The daily volumes appear by water year, October 1 - September 30, followed by the monthly and annual totals. Codes indicating estimated flows, flows exceeding gage limits, very small flows (trace), and inflows too small to measure (water in pool) follow the applicable daily values, and are described briefly in the legend at the bottom of the summary sheet.

Program Logic

The following discussion is intended to describe the general logic of the program in the order shown in figure 3. The description is not necessarily in the sequence of operations followed in the program.

Rating tables are separate from the program deck itself, but must always follow the program deck in the indicated order whether they are to be used or not during that particular run. Once read into the computer, the rating tables cannot be changed.

Control for processing individual water year records is contained on the station identification (SID) card which follows the rating table cards. Failure to provide the control data on the identification card (table 1) will trigger a stop and cause a system error message to be printed on the output sheet.

The three summary cards are next read into the computer. If no information is punched on the cards, printed lines 1, 3, and 8 on the summary will remain blank.

The next card (first data card for a water year) carries a 00 hour 00 minute time entry to indicate the midnight starting point and the beginning of a new water year of compilations. Military time, to the nearest minute, is used throughout. Each day of compilation ends, and is summarized, with a midnight (24 hour 00 minute) data card. Except at the beginning of a water year or portion of a water year, the midnight data point also serves as the starting point for the following day. Times on succeeding cards are checked for sequence as they are read in until a complete day's data are stored.

A streamflow volume for each interval within the day is then computed either by formula or by rating table. Method and formula for computing are set by the station number and type of gage appearing on the station identification card and, thus, remain consistent within each station year.

Initial selection of method for each gage was based on its type of rating. Gage heights on succeeding data cards represent points on the hydrograph between which connecting straight-line segments would either follow or adequately represent the trace. Where the computations for a particular stream gage are based on a formula rating with a single fixed power value of the head over its entire range, an accurate integrating formula, similar to that proposed by Bethlahmy,[4] is used in the computations for each interval (represented by a line segment). When instantaneous rates of flow are related to head in an empirical rating table, discharge rates at the beginning and end of the interval are averaged in computing volumes, and the computation is less accurate. The relative difference in discharge computed by the two methods for such a line segment is shown in figure 4. Accuracy of the averaging method can be improved by increasing the number of gage height points so that the change in head values between points is reduced.

Some rating tables contain abrupt changes in the head-power relationship. With such tables, additional errors in computation occur when the interval between gage heights carries from one power relationship to another. Error may be minimized by picking a point on or near the change.

Formulas for the two methods of computing are:

Rating by Formula	**Rating by Table**
$Q_i = CH_i^{D}$	Q_i = from rating table
$Q_{av}{*} = \dfrac{(C)(H_2^{D+1} - H_1^{D+1})}{(D+1)(H_2 - H_1)}$	$Q_{av}{**} = \dfrac{Q_1 + Q_2}{2}$
$Q_{int} = Q_{av}(T_2 - T_1)$	$Q_{int} = Q_{av}(T_2 - T_1)$

WHERE Q_i = instantaneous rate of flow for given H_i ,
C, D, = gage constants,
H_i = instantaneous head or depth above zero datum flow,
T_i = time
i = 1,2 beginning and end of interval, respectively,
Q_{av} = average rate of flow for interval,
Q_{int} = total flow for the interval.

* IF: $H_2 = H_1$ then $Q_{av} = Q_1 = Q_2$

** This formula is equivalent to

$$\frac{C(H_2^{D+1} - H_1^{D+1})}{(D+1)(H_2 - H_1)} \quad \text{for } D = 1$$

---

[4] *Bethlahmy, Nedavia. Improved procedure for calculating stream discharge. U.S. Forest Serv. Res. Pap. PNW-10, 6 p. 1964. Pacific Northwest Forest and Range Exp. Sta., Portland, Oreg.*

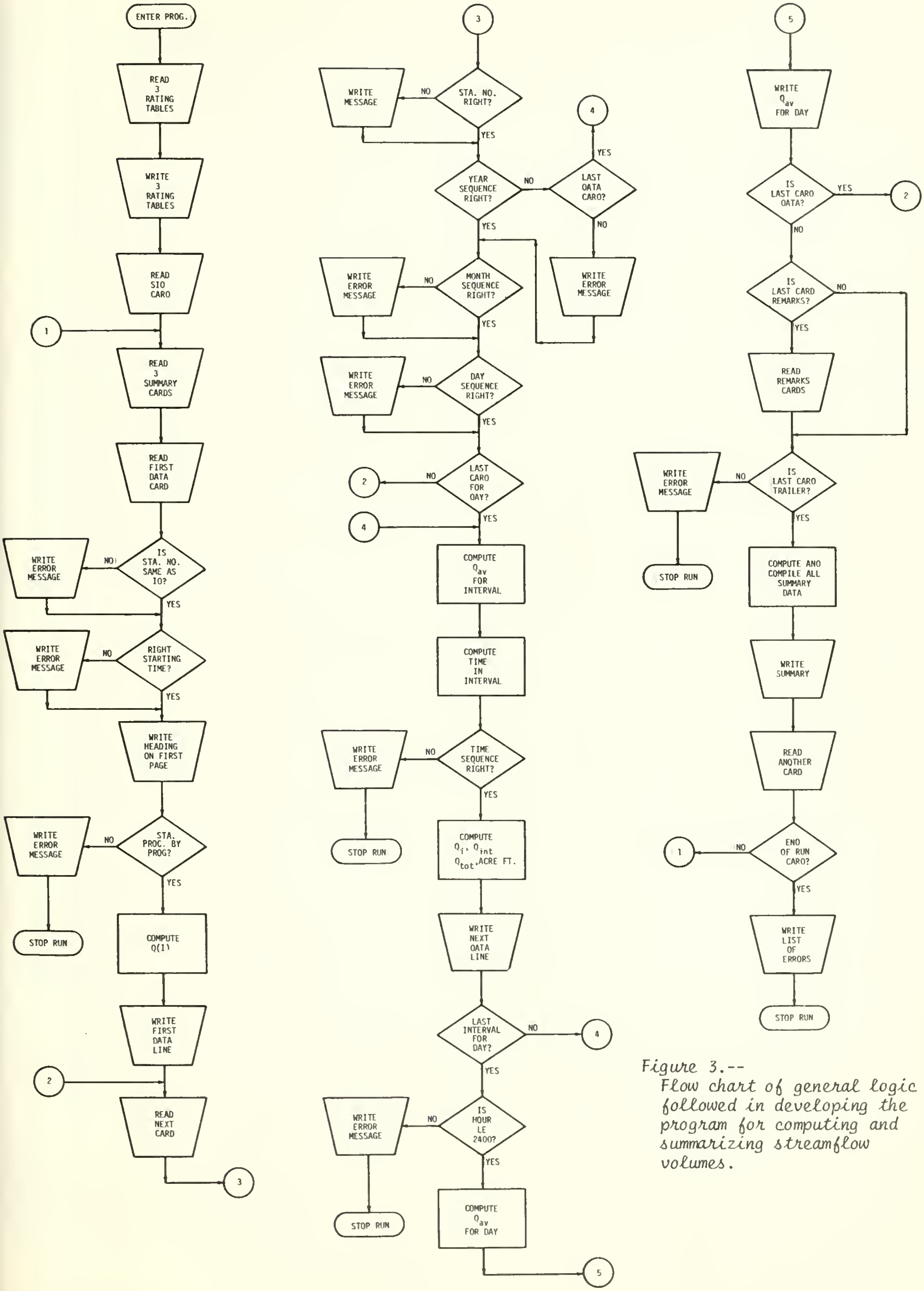


Figure 3.--
Flow chart of general logic followed in developing the program for computing and summarizing streamflow volumes.

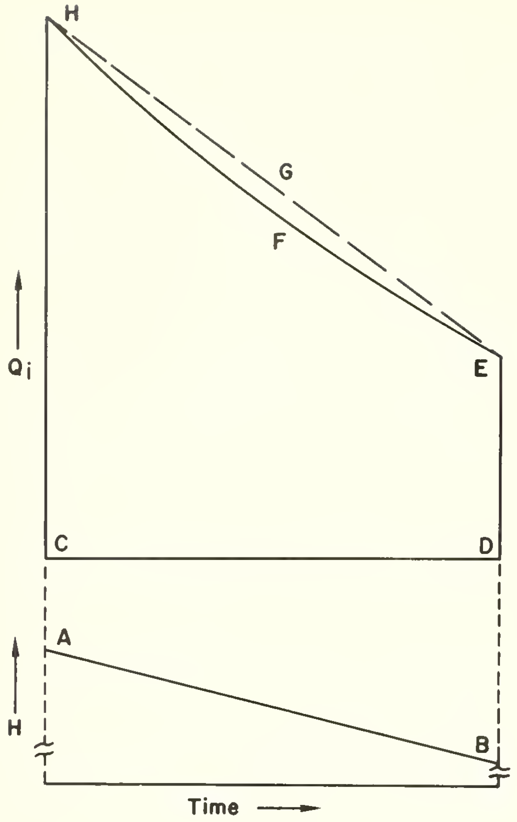


Figure 4.--For the section of straight-line trace AB, the actual volume of flow (computed by the integration formula) is represented by the area CDEFH. The volume as computed by the rating table method is represented by area CDEGH.

Rating tables contain Q_i values for 0.01-foot head increments. The computer interpolates linearly when necessary to determine intermediate 0.001-foot head increment values. When a gage height exceeding the limit of a rating table is recorded, the program automatically sets the Q_i for that gage height equal to the highest Q_i in the table (the limit). Thus the size of a rating table must be determined carefully. Printout follows the computation of volumes for each interval until the day ends, when the total is expressed in a printout of the average rate of flow for the day.

An optional remarks code card can follow the last card of a data set. If used, it is read in after streamflow volumes are computed, thus signaling the computer that a defined number of remarks cards follow it. These cards are read, and printed out following the word "REMARKS" on the station summary.

A trailer card must follow the data cards or any remarks cards. The code in column 5 indicates the unit of volume to be printed in the one-sheet summary. If additional summaries are desired, a trailer card with applicable code is added for each.

The presence of the trailer card also signals the ending of daily streamflow computations for a water year, and time to assemble and print the summary. Unless the next card is another trailer card or the "end-of-run" card, it will be an SID card and control will return to the processing of another year's data.

Program Stops and Messages

Program stops and error messages are of three types. Certain errors are responsible for each:

1. Computer stop plus program message with error location occurs when:
   a. The given station number is not processed by this program.
   b. The month number on the data card is greater than 12.
   c. The 2400 hour gage height for the day is missing.
   d. A time in the day is greater than 2400.
   e. A time in the day is out of sequence.
   f. The trailer card following the station year has a number other than 1, 2, 3, or 4 in card column 5.
2. Incorrect reduction and compilation of data plus program message with error location occurs when:
   a. Watershed number on first data card does not match watershed number on ID card.
   b. First data card is not dated 10-01-XX at 0000 hour.
   c. Date advances from 12-31 to 01-01 without advancing the year.
   d. Transition from one year to the next is incorrect.
   e. The watershed number is in error.
   f. Transition from one month to the next is incorrect.
   g. The month or day is out of sequence.
   h. The number of days in the month is incorrect.
   i. A duplicate time occurs within the day.
3. Computer stop plus system error message (certain data cards are out of place or missing). Processed data to this point are printed out when:
   a. One or more rating tables are out of place or missing.
   b. Station identification card is out of place or missing.
   c. No trailer card follows a station year of streamflow data.
   d. End-of-run card is out of place or missing.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-204

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

A Portable Light Table for Field Interpretation of Aerial Photographs

H. Dennison Parker, Jr.[1]

Interpretation of aerial photography often requires on-site investigation of the surface features imaged on the photos. A portable light table that accommodates two, 70 mm. film spools or one 9- by 9-inch transparency, was constructed. The unit is powered by self-contained rechargeable batteries or from external 115 VAC or 12 VDC sources.

KEY WORDS: Aerial photography, light table.

Interpretation of photographs taken from rcraft or earth-orbiting satellites often requires -the-ground investigation of the area being udied to assure positive identification of spe- fic targets. Due to losses in image quality hen photos are duplicated or printed, it is sirable to use the original film transparencies these investigations.

To aid in field interpretation of aerial photo- aphs, a battery-powered, rechargeable light ble was constructed. The table was spe- fically designed to display 70 mm. film trans- rencies, since this film size is most often ed in photographs from satellites and from rcraft when large-scale imagery is required r individual object identification or for mpling purposes (Aldrich 1966, Driscoll 1969).

Description

The light table (fig. 1) was designed to accommodate two 70 mm. film rolls simultaneously, to permit field comparison of imagery obtained on two different film types. The viewing stage is an 8- by 8-inch area of opaque, acrylic plastic (fig. 2) illuminated by six fluorescent tubes. These tubes may be operated three or six at a time, thus lighting half or all of the viewing surface. Field power is supplied by a built-in, 12-volt, rechargeable battery pack which will power the light source for up to approximately 1 hour of continuous use. The table may also be operated from any 115 VAC 60-cycle line, or from an external 12 VDC supply. An accessory cord, provided with the table, may be plugged into any automotive cigarette lighter outlet for operation in this mode. A hi/lo light intensity control permits a reduction in power consumption when brightest lighting is not required. A battery charger built into the unit allows recharging where-

---

[1] *Range Technician, Rocky Mountain Forest d Range Experiment Station, with central adquarters maintained at Fort Collins in co- eration with Colorado State University.*

Figure 1.--
The light table can accommodate two reels of 70 mm. film or one 9- by 9-inch transparency.

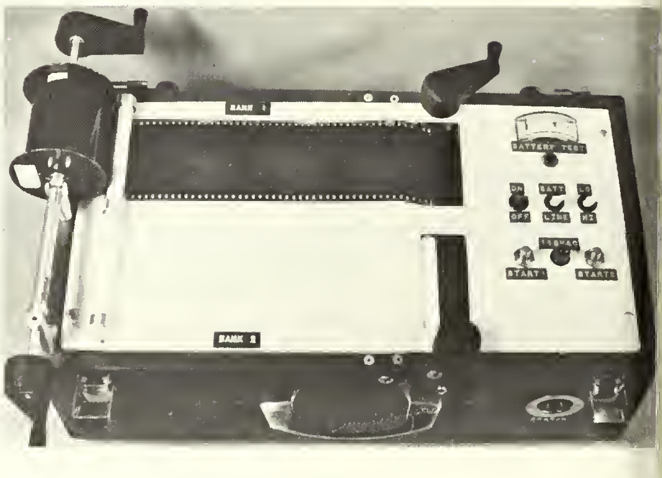

Figure 2.--
Power for the six fluorescent tubes may be supplied by a built-in rechargeable battery pack, from an external 12-volt battery, or from any 115-volt outlet.

ever standard 115 VAC power is available. The unit measures 7½ by 9½ by 16½ inches, and weighs about 22 pounds.

Construction Details

The battery pack consists of ten 1.2-volt nickel-cadmium cells, factory assembled in a series network to provide a 12.5 volt pack (G.E. Type 10GR4).[2] A 12 VDC/115 VAC power inverter is used to provide the 115 VAC required for the fluorescent tubes.

The unit is wired as shown in figure 3. The use of battery or external 115-volt power is controlled with a toggle switch, S3. If battery power is used, the inverter is then turne on with another toggle switch, S2. In eithe battery or external mode, 115 VAC is indicate by the panel lamp, L1.

The fluorescent tubes are started in tw groups of three with switches S5 and S6. Th switches are held for 3 to 5 seconds, the released. Once in operation, power may b conserved by switching the hi/lo intensity switc to "lo" position. This switch (S4) places 200-ohm, 50-watt resistor in series with th fluorescent tubes.

The film takeup reels, located underneat the viewing stage (fig. 4), are standard, 50-fo 70 mm. film spools, with small spines protrudin from the centers which provide for automat film takeup. The spines were formed by ben ing out a small area of the aluminum cent

[2] Trade and company names are used for the benefit of the reader, and do not constitute endorsement or preferential treatment by the U. S. Department of Agriculture.

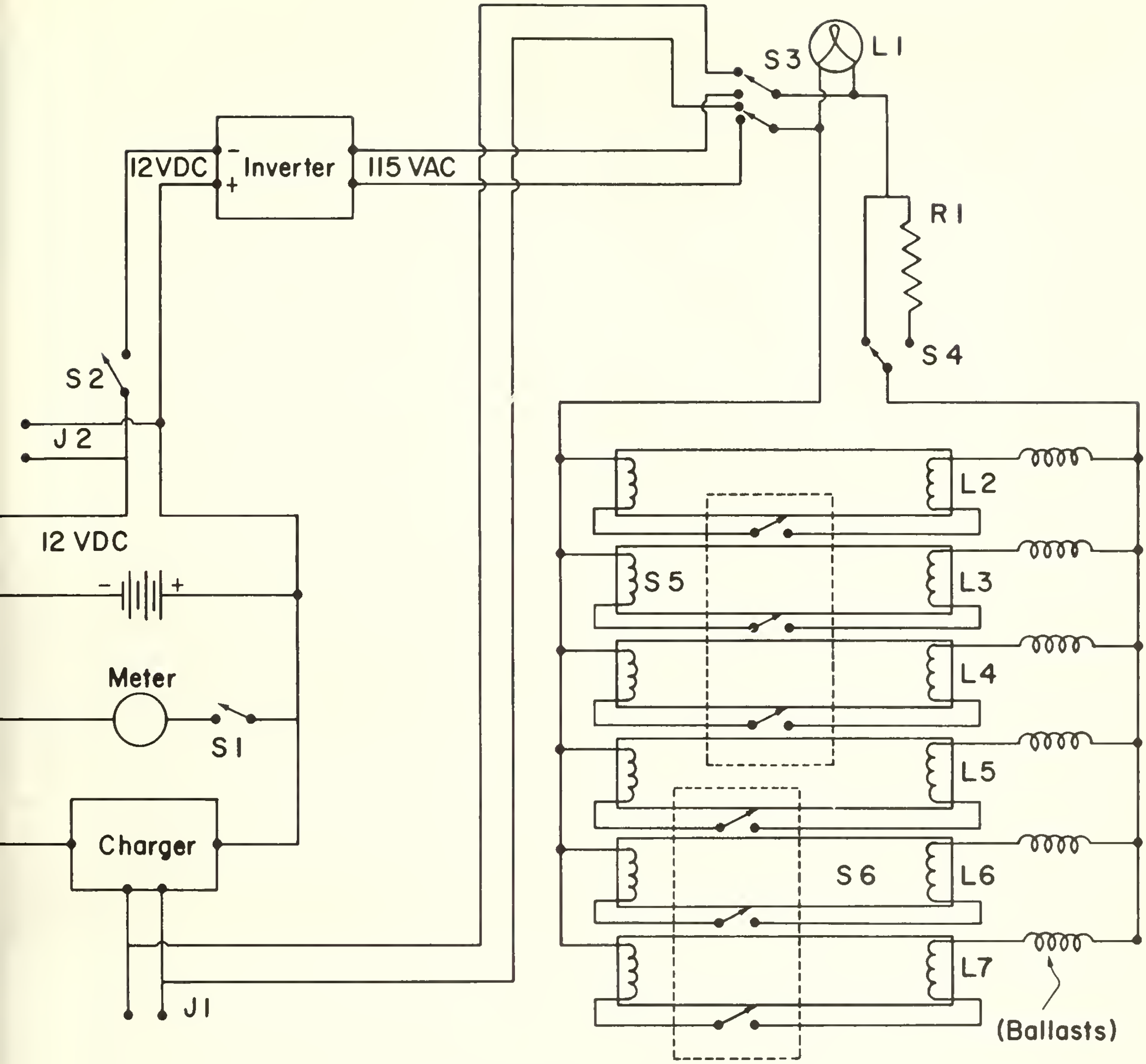

Figure 3.--Circuit diagram and parts list for portable light table.

S1--Battery Test Switch, SPST, N.O., pushbutton.
S2--Inverter on/off Switch, SPST, toggle.
S3--Internal/External 115 VAC Switch, DPDT, toggle.
S4--Hi/Lo Light Intensity Switch, DPST, toggle.
S5, S6--Fluorescent Tube Starters, TPST, N.O., pushbutton.
R1--200 ohm, 50 watt.
L1--Panel Lamp, neon.

J1--115 VAC Connection.
J2--External 12·VDC Connection.
L2, L3, L4, L5, L6, L7--Fluorescent Tubes, G. E. Type F6T5CW.
Ballasts--40 watt, G. E. Type L-140F.
Battery--12.50 volts, 4.4 amp-hour, G. E. Type 10GR4.
Meter--0-15 VDC.
Charger--500 MA, Electronic Components Co., Type 10-500.
Inverter--12 VDC to 115 VAC.

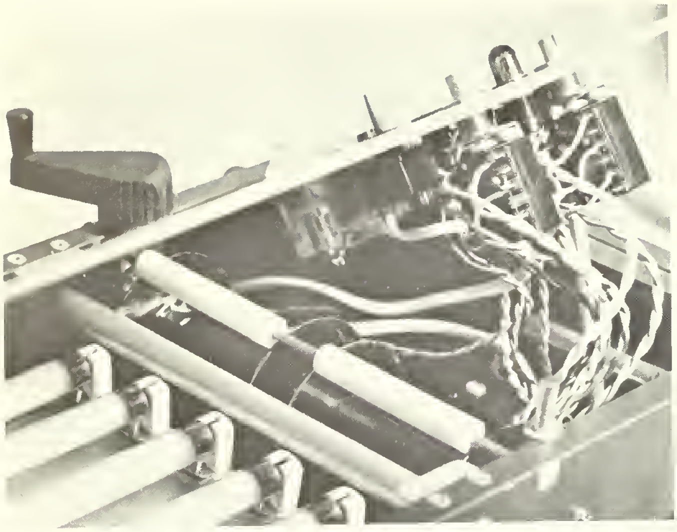

Figure 4.--

The automatic film takeup reels are located beneath the viewing stage.

spindle with needle-nosed pliers, then filing to produce the desired size and shape. In operation, the end of each film roll is inserted into the takeup slot, and the takeup reels turned slowly, allowing the spines to engage the sprocket holes in the film. Two right-angle gear drive units are used to couple the takeup reels to the hand cranks. The film feed reels are positioned on removable shafts, which are stored in the lid when not in use.

The film rollers were made from teflon rod, an ideal material for this purpose because of its "self-lubricating" characteristic.

Discussion

The design of the field light table could be modified in a number of ways to better suit any specific application. The nickel-cadmium batteries could be replaced by standard carbon-zinc (nonrechargeable) batteries, at considerable cost savings. Or, batteries could be omitted entirely, in favor of using vehicle (12 VDC) power.

If only one or two fluorescent tubes are needed, the 12 VDC/115 VAC inverter could be replaced by "inverter-ballasts," that develop 115 VAC from 12 VDC for each fluorescent tube separately. The total current drain in either case is the critical factor. When six fluorescent tubes are used, it is more economical, in terms of power consumption, to use the separate inverter.

The film transport system is not discussed in detail because its design would probably depend on the individual application and on the shop facilities available for its construction.

Two very useful accessories to the light table are a stereoscope and a viewing hood. The stereoscope used was a 2-power model which simply rested on the viewing stage. The hood was made of a piece of black corduroy large enough to cover the user's head while at the light table, thus excluding glare from the sun. Among other accessories which could be added are a tripod mount, and a glass plate for holding the film flat against the viewing stage. The viewing stage is sufficiently large to provide single-frame interpretation of larger aerial photographs, up to 9 by 9 inches. This feature is very useful when 70 mm. photographs are used in conjunction with larger format, smaller scale imagery in sampling problems.

The model described is a prototype, and therefore the cost of construction may not be representative. It is expected, however, that the cost of materials to make a similar light table would be about $250, depending on local prices.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 205

EST SERVICE
DEPARTMENT OF AGRICULTURE

Y MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Effects of Extractives on Specific Gravity of Southwestern Ponderosa Pine

Roland L. Barger and Peter F. Ffolliott[1]

Specific gravity is the simplest and most useful single index to the suitability of wood for many uses. In resinous species, however, the presence of extractives results in a higher specific gravity than warranted by cell wall substance alone, introducing a systematic error into estimated strength characteristics and pulp yields. The results of this study indicate that mean specific gravity of southwestern ponderosa pine is reduced approximately 12 percent (0.421 to 0.371) by the removal of alcohol-, benzene-, and water-soluble extractives. Extracted specific gravity can be estimated from measures of unextracted specific gravity by the equation Y *(Ext. Sp. Gr.) = 0.593 - 0.092 /* X *(Unext. Sp. Gr.). Quantity of extractives was the only measured tree characteristic found to contribute significantly to variation in unextracted specific gravity.*

KEY WORDS: *Pinus ponderosa*, density, extracts.

Specific gravity is a useful index to the uitability of wood for many uses. Specific ravity largely determines yields of such prodcts as pulp and charcoal, and is closely correited with mechanical strength. It also provides ome idea of the working properties and finishng characteristics of wood.

The specific gravity of wood cell wall subtance has been found relatively constant at .53 regardless of species (McKimmey 1959, Iitchell 1965). Since wood is a cellular mateial, however, specific gravity may vary among pecies and trees within a species group. Variaon is due to differences in proportion of the wood made up of cell walls and included infiltrates or extractives.

The presence of extractive components may increase both magnitude and variability of specific gravity for resinous species such as ponderosa pine (Pinus ponderosa Laws.) (Paul 1955, U.S. Forest Serv. 1965a, Voorhies 1969). Since strength characteristics and pulp yields are a function of cell wall substance only, estimates based on "unextracted" specific gravity may be somewhat high.

The Study

The study was designed to determine specific gravity variation in a range of ponderosa pine forest density conditions, age and size class intermixtures, and volume distributions common to Arizona. Specific objectives were to: (1) determine specific gravity of unextracted sample material; (2) determine specific gravity of the same sample material after removal of all alcohol-, benzene-, and water-soluble extrac-

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[1] *Principal Wood Technologist and Associate ilviculturist, respectively, located at Flagtaff in cooperation with Northern Arizona niversity when research work was conducted. tation's central headquarters is maintained at ort Collins in cooperation with Colorado State niversity. Dr. Ffolliott is now Assistant rofessor, University of Arizona, Tucson.*

tives; (3) describe the effect of included extractives upon the magnitude of unextracted specific gravity; and (4) investigate the association between specific gravity values and commonly employed measures of tree and stand characteristics.

Specific gravity was determined from increment cores taken at breast height (4.5 feet); consequently, all values are indicative of specific gravity at **breast height** rather than for the tree as a whole. For most conifers, however, unextracted specific gravity decreases only slightly with increase in height (U.S. Forest Serv. 1965b, Wahlgren and Fassnacht 1959).

Field Procedures

Full-length increment cores were collected from 442 ponderosa pine trees as part of a timber quality inventory of three experimental areas in Arizona: the Beaver Creek watersheds, the Long Valley Experimental Forest, and the West Fork Castle Creek watershed. Inventory procedures were based on point sampling techniques, with an increment core taken from one tree at each sample point. Supplementary data describing tree and stand characteristics were available from the inventory.

The sample areas represent a broad range of ponderosa pine site quality. The Beaver Creek watersheds, 45 miles south of Flagstaff, contain lower quality cutover stands, with an estimated site index (Meyer 1961) of 45 to 60 feet at 100 years. The Long Valley Experimental Forest, 65 miles southeast of Flagstaff, represents the better timber-growing sites, with a site index of 85 to 90 feet, and at the time of sampling was one of the few remaining stands of virgin ponderosa pine in Arizona. The West Fork Castle Creek watershed, 12 miles southwest of Alpine, is considered a good timber-growing area, with a site index range of 65 to 80 feet.

Laboratory Procedures

Unextracted specific gravity (green volume-ovendry weight) was determined for each increment core by the weight-volume method (U.S. Forest Serv. 1956). Green volume was obtained by submerging single cores in a container of water and measuring the displacement. The cores were then ovendried at 105° C, weighed, and specific gravity calculated.

To remove soluble extractives, the increment cores were placed in a Soxhlet extractor (fig. 1). A solvent solution of one-third ethyl alcohol and two-thirds benzene was refluxe over the cores for 24 hours.[2] The cores wer then removed from the extractor and submerge in boiling distilled water for 4 hours to remov water soluble extractives.

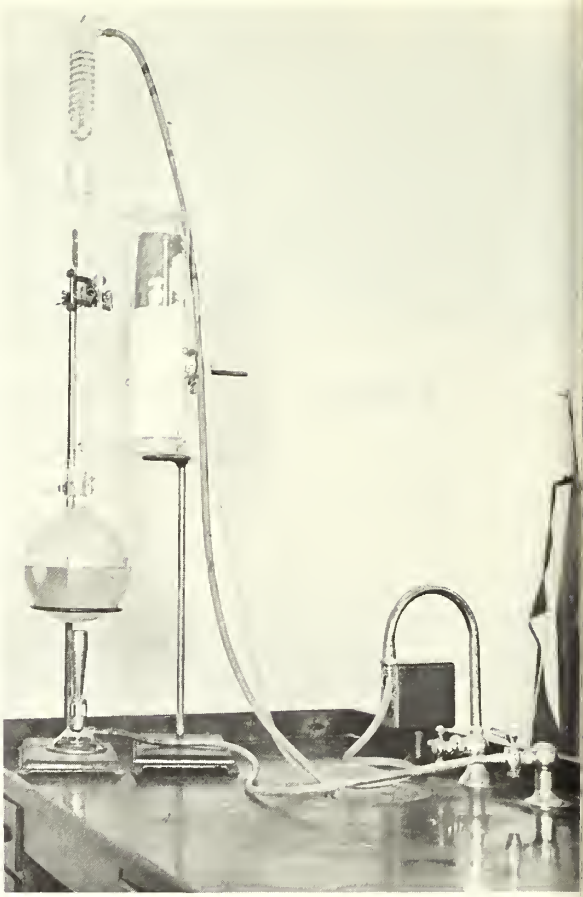

Figure 1.--A modified Soxhlet extractor, pr vided by the School of Forestry, Northe Arizona University, was used to perform t extractions.

Extracted increment cores were saturate with water under vacuum, and their specifi gravity determined by the maximum moistur content method (Smith 1954). The cores wer then ovendried at 105° C , weighed, and thei specific gravity was again computed by th weight-volume method. Values obtained b the maximum moisture content method serve as a check on values determined by the weigh volume method, which were used in subs quent analysis.

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[2] Cores extracted according to procedur developed by Professor Glenn Voorhies, Schc of Forestry, Northern Arizona University, Fla-staff, and with extraction equipment provic by the School of Forestry.

Analysis and Results

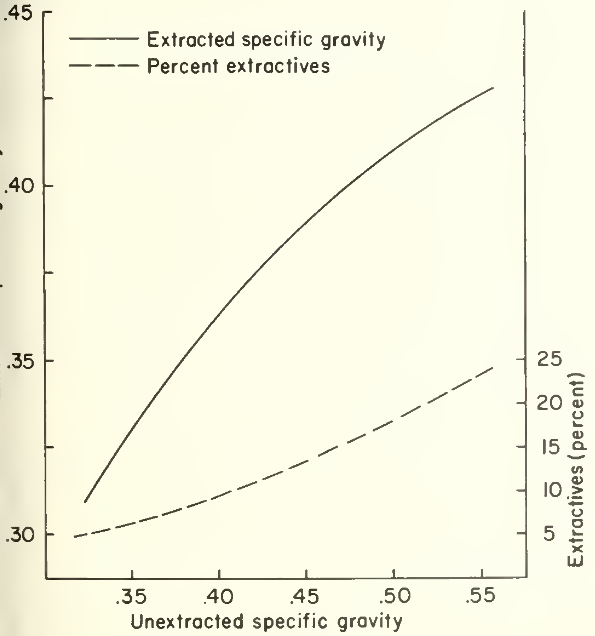
Preliminary analysis of specific gravity data ndicated no significant differences among areas; onsequently, data were combined in all nalyses. Specific gravity values for the total ample were:

	Minimum	Mean	Maximum
rior to extraction	0.308	0.421	0.621
ollowing extraction	.283	.371	.500

hese values agree with values of 0.416 (unexracted) and 0.374 (extracted) reported for younggrowth ponderosa pine site trees by Voorhies 1969).

Although extraction reduced the range of ariation in specific gravity, relative variation mong sample cores did not change significantly. oefficients of variation before and after extracion were 11.8 and 9.5 percent, respectively.

In using specific gravity as an index of ood quality or product yield, it is frequently esirable to estimate extracted specific gravity or quantity of extractives) from unextracted pecific gravity. To develop a basis for such stimates, regressions were calculated relating xtracted specific gravity and quantity of extracives to unextracted specific gravity (fig. 2).



igure 2.--Unextracted specific gravity provides a basis for estimating extracted specific gravity and quantity of extractives, important in predicting wood quality and fiber product yields.

The empirical equations describing these relationships are:

$$\hat{Y} = 0.593 - 0.092/X \qquad (r^2 = 0.50) \tag{1}$$

where

$\hat{Y}$ = predicted extracted specific gravity
X = unextracted specific gravity

$$\hat{Y} = -73.320 + 10.615/X + 140.504X \quad (r^2 = 0.35) \tag{2}$$

where

$\hat{Y}$ = predicted percent extractives
X = unextracted specific gravity.

These equations can be used with unextracted specific gravity values to estimate quantities of extractives soluble in alcohol, benzene, and water, and to reduce error in estimating such characteristics as wood strength and pulp yields.

Possible correlations between specific gravity and measured tree and stand characteristics were tested. Six characterisitics, reported to be correlated with specific gravity elsewhere (McKimmey 1959, Mitchell 1965, Paul 1963, Thor 1964), were analyzed:

1. Diameter breast high (inches).
2. Tree volume (cubic feet computed as vol. = $0.00545fD^2H$, where form factor (f) = 0.42).
3. Age at breast height (expressed as the reciprocal, 1/age).
4. Quantity of extractives (percent, as measured in core extractions).
5. Growth rate (expressed as dia./age).
6. Forest density (expressed as number of trees tallied at sample point with an angle gage corresponding to BAF=25).

Of these, only the first four were significantly related to one or both measures of specific gravity (table 1), and the only reasonably strong association was between percent extractives and unextracted specific gravity. Combining independent variables in multiple regression fashion did not significantly improve the correlations.

Conclusions

1. The mean specific gravity of ponderosa pine is reduced approximately 12 percent (0.421 to 0.371) by the removal of alcohol-, benzene-, and water-soluble extractives.
2. Empirical equations can be used to estimate extracted specific gravity from measures of unextracted specific gravity, thereby improv-

Table 1.--Correlations between specific gravity and independent variables significantly related to one or both measures of specific gravity[1]

Independent variable	Range of sample			Coefficient of determination related to --	
	Minimum	Mean	Maximum	Unextracted specific gravity	Extracted specific gravity
Diameter breast high (inches)	3.1	15.9	52.9	ns	0.03
Tree volume (cubic feet)	1.2	64.2	500.0	ns	.02
Reciprocal of age (1/years)	.003	.015	.053	-0.03	-.04
Quantity of extractives (percent)	0.3	11.4	39.4	.35	.03

[1] Significance judged at the $\alpha = 0.05$ level.

ing estimates of such characteristics as wood strength and pulp yields.

3. Correlations between commonly measured tree and stand characteristics and specific gravity are weak, and of no practical value in identifying causes of variation in specific gravity.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-206

REST SERVICE
. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Soil Water Availability in an Arizona Mixed Conifer Clearcutting

Robert S. Embry[1]

Only under grass on level and southerly exposures did soil moisture deficits approach or exceed the permanent wilting point. Under burned and scalped surfaces, adequate moisture was available for the survival of established seedlings and planted stock throughout the growing season on all exposures.

KEY WORDS: Soil moisture, plant water relations, mixed conifers.

Mixed conifer forests in the Arizona White Mountains include eight commercial timber species: Engelmann spruce (*Picea engelmannii*), blue spruce (*Picea pungens*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), corkbark fir (*Abies lasiocarpa* var. *arizonica*), ponderosa pine (*Pinus ponderosa*), southwestern white pine (*Pinus strobiformis*), and quaking aspen (*Populus tremuloides*).

Clearcutting has been a major method of harvesting these mixed forests. Natural regeneration and limited artificial regeneration trials have not been successful. Jones (1967) suggested that animal pests and inadequate soil moisture were important in influencing the amount and composition of postlogging regeneration. Herbaceous plants were considered to compete primarily for soil moisture. Drought may have contributed to the high mortality of Douglas-fir, true fir, and spruce seedlings on seedbeds with little or no herbaceous vegetation.

We studied soil water availability during the growing season in a mixed conifer clearcutting so that managers could obtain a better understanding of how soil moisture may affect the regeneration problem.

The Study Area

The study was conducted in 1970 in a commercially clearcut stand in east-central Arizona at an elevation of 9,200 feet. The stand was logged in 1966, and all slash and unmerchantable residual trees were windrowed and burned. Grass[2] was seeded in the areas between the slash windrows at the time of piling.

Soils are of basaltic origin and are well drained, moderately well developed, and moderately fine textured (Leven et al. 1967).

Summers are cool, with temperatures seldom reaching 80° F. Annual precipitation falls mostly in summer and winter; spring precipitation is low. The 10-year average annual and average April-June precipitation at the nearest permanent weather station, 5.5 miles north, is 29.37 inches and 2.61 inches, respectively. Total precipitation for 1970 was 23.57 inches; the 1970 April-June total was 2.18 inches (table 1).

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[1] *Associate Silviculturist, located at Flagstaff in cooperation with Northern Arizona University. The Station's central headquarters is maintained at Fort Collins in cooperation with Colorado State University. Embry is now with St. Joe National Forest, St. Maries, Idaho.*

[2] *The following grasses were seeded on these cutovers: smooth brome, Bromus inermis; perennial ryegrass, Lolium perenne; orchardgrass, Dactylis glomerata; pubescent wheatgrass, Agropyron trichophorum.*

Table 1.--Study site climatic summary--1970

Period ending date	Precipitation for period	Precipitation cumulative	Temperature Maximum	Temperature Minimum	Temperature Average
	- - Inches - -		- - - - - °F. - - - - -		
Apr 13	--	--	--	--	--
20	0.54	0.54	50	20	35.0
27	0	.54	56	19	37.5
May 4	0	.54	55	12	33.5
11	0	.54	62	31	46.5
18	0	.54	70	37	53.5
25	0	.54	71	41	56.0
Jun 1	.55	1.09	69	32	50.5
8	.06	1.15	67	37	52.0
16	.02	1.17	66	36	51.0
22	.02	1.19	77	46	61.5
29	.62	1.81	79	45	62.0
Jul 6	.37	2.18	75	43	59.0
13	.93	3.11	78	46	62.0
20	.31	3.42	81	47	64.0
27	3.46	6.88	71	44	57.5
Aug 3	.81	7.69	74	47	60.5
10	1.02	8.71	71	46	58.5
17	.93	9.64	71	46	58.5
24	1.72	11.36	69	46	57.5
31	.26	11.62	73	45	59.0
Sep 8	4.15	15.77	71	42	56.5
14	.30	16.07	69	44	56.5
21	0	16.07	66	36	51.0
30	.05	16.12	64	30	47.0

Snow is retained into April or May on north slopes. South slopes are often partly bare during the winter, but retain partial snow cover into March or April.

Methods

Treatments

Three soil surface conditions were studied on three exposures. The surface conditions were:

1. **Burned**—plots were located where piled slash had been burned in 1966. All unburned material was removed.
2. **Scalped**—all vegetation (grass) was scraped off with a small tractor and blade.
3. **Grass**—plots were established in the areas that had been seeded to grass in 1966.

The exposures sampled were: (1) a 24-percent NNE slope; (2) a 16-percent WSW slope; and (3) a level area.

Surface treatments were established on adjacent 42-foot-square plots on each exposure. Actual sampling was done on a 14-foot-square plot in the center of each treatment plot.

Sampling

Soil moisture content measurements were begun on May 14, 1970. On each sampling date, a soil auger was used to collect samples from depths of 0-4, 4-8, 8-12, and 12-16 inches from two locations on each treatment plot Larger gravels, estimated over 1/4 inch, were discarded.

Bulk samples were collected from the border zones on each exposure site. These samples were used for matric potential determination and textural analyses.

Laboratory Analyses and Computations

Soil moisture was determined gravimetrically.

The best measure of soil water availability is the water potential. The principal components of the soil water potential are the matric and solute (osmotic) potentials. In soils low in solutes, the matric potential may be used to express the availability of water to plants. Matric potential is commonly expressed in standard atmospheres or bars.[3] Soil-water terminology and relationships are discussed in detail in Kramer (1969).

Soil moisture retained at 1/10, 1/3, 1, 2-1/4 5, 10, and 15 bars of pressure was determined with a 15-bar ceramic plate extractor. All samples used in this determination were air dried and passed through a 2 mm sieve. Equations for estimating matric potential from measured field moisture content were calculated For each exposure-depth sampled, a linear regression based on fixed x as above was calculated:

$$\operatorname{Ln} y = a + b \operatorname{Ln} x$$

where

y = moisture content of soil (ovendry basis) in percent,
x = matric potential in bars.

Samples for textural analyses were air-dried and passed through a 2 mm sieve. Particle size distributions into sand, silt, and clay were determined by the Bouyoucos (1951) hydromet

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[3] 1 bar = 0.987 atmosphere.

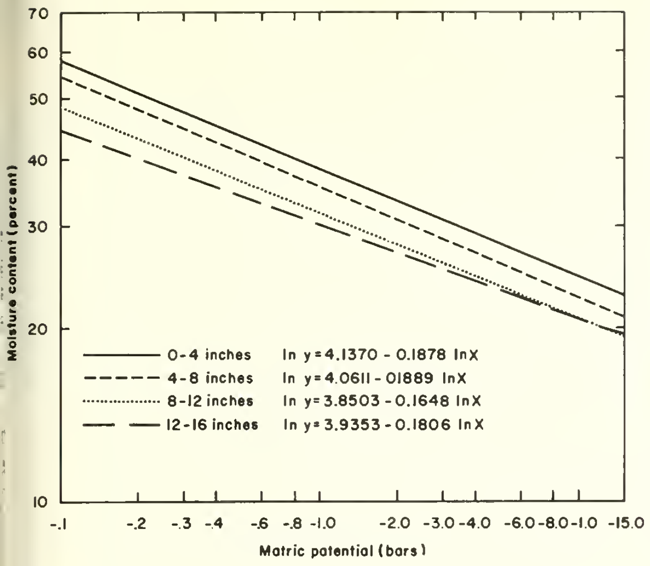

Figure 1.--Moisture retention curves for soils in a mixed conifer clearcutting in east-central Arizona.

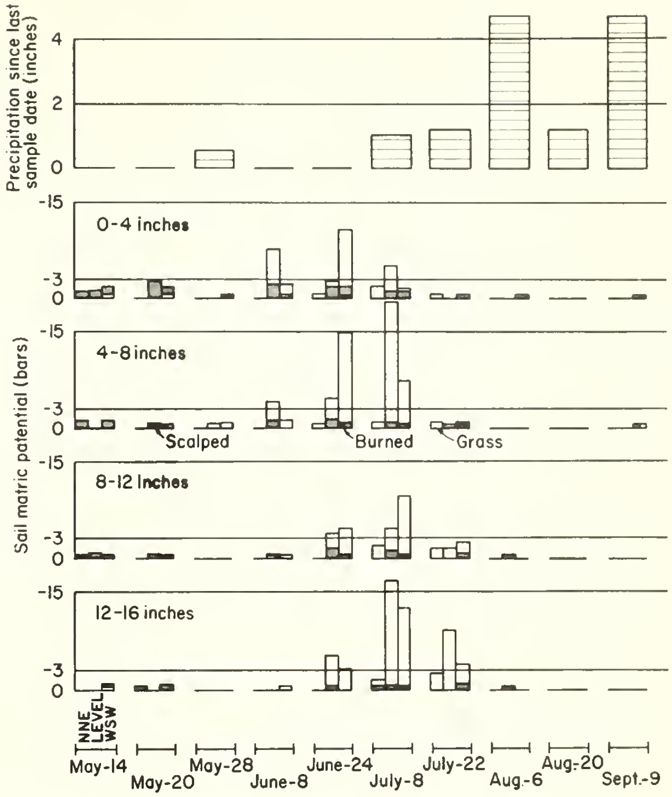

Figure 2.--Precipitation and matric potential of soils from a mixed conifer clearcutting in east-central Arizona.

method. Distributions were quite uniform for all depths and locations. All the samples were classified as silty-clay-loam. Average sand, silt, and clay distributions were 13, 54, and 33 percent, respectively.

Results

The regressions of soil moisture content on matric potential for a given depth did not differ significantly between exposures. Therefore, the exposure data were combined by depth into four estimating equations (fig. 1). Correlation coefficients for these regressions are significant at the 99 percent level. The r^2 values range from 0.88 to 0.90 and the standard errors from 1.13 to 1.10.

Computed matric potentials are shown by exposure and sampling date in figure 2.

Burned plots.—Matric potentials were consistently higher under the burned plots than under the other surface treatments. A minimum potential of -0.72 bar was recorded June 24 on the WSW exposure in the 4-8 inch layer.

Scalped plots.—Matric potentials dropped to -2 bars only twice under the scalped plots, both in the 0- to 4-inch depth on the level exposure. In general, matric potentials were lower early in the season under scalped surfaces than under the other surface treatments. This was especially noticeable in the 0- to 4-inch depth on the level and WSW exposures. Differences in matric potentials were not significant under scalped plots for any of the treatment combinations. Somewhat lower potentials were measured on the level sites than the WSW sites.

Grass plots.—Only under grass plots did matric potentials drop to or below -15 bars. This occurred on only two dates—the last week in June and the first week in July (fig. 2). Significant decreases in matric potentials were measured in the 0- to 4-inch depth on the level plots on June 8 and on the WSW sites on June 24. These lower matric potentials persisted through July 22 on both exposures in the 12- to 16-inch depth. The onset of summer rains immediately increased matric potentials in the surface 4 inches, and by July 22 matric potentials in the upper 12 inches indicated that water stresses were negligible.

Discussion

A matric potential of -15 bars has been used as the point of permanent wilting (death) for many plants, but the point at which soil moisture deficits actually begin inhibiting growth is not so standardized. Glerum and Pierpoint (1968) found that terminal leader and diameter growth of 3-0 red pine (Pinus resinosa) and larch (Larix laricina) were significantly reduced by matric potentials of -15 bars, while potentials of -1 and -6 bars had little effect. White spruce (Picea glauca) of the same age was not significantly affected by potentials of -1, -6, or -15 bars.

Spring flush height growth of 9-month-old seedlings of loblolly (Pinus taeda) and shortleaf pine (Pinus echinata) was inhibited by matric potentials of -2 bars, and stopped completely at -3.5 bars (Stransky and Wilson 1964). The young flush began to wilt near -5 bars.

Sands and Rutter (1959) found a significant reduction in growth in first-year scotch pine (Pinus sylvestris) grown in soil at -0.3 bar as compared to those grown at -0.1 bar. In 3-year-old seedlings, the growth reduction occurred between matric potentials of -0.5 and -1.5 bars.

Data on how soil moisture availability influences mixed conifer seedling growth are not available. The above studies indicate that growth may be inhibited by relatively high matric potentials of between -0.3 and -5 bars. Seedlings probably are not killed, however, until the matric potential approaches -15 bars.

Soil moisture conditions that might adversely affect the survival of established seedlings or planted stock are not likely to occur on burned or scalped mixed conifer cutovers on any of the exposures studied.

Seed germination and survival of newly germinated seedlings are likely to be poor in the early spring due to generally lower matric potentials in the 0- to 4-inch depth, especially under scalped surfaces. The soil surface dries out very rapidly in the spring due to the continuous dry winds. This dry surface may act as a moisture barrier and help retain deeper soil moisture throughout the spring dry period. The same situation probably is true on the burned surfaces, only the ash mulch apparently is more effective.

Except in spring, grass areas have the least favorable moisture environment for the survival and growth of seedlings; matric potentials of -15 bars were measured. When the grass is not yet actively growing in spring, it seems to shade the surface and actually helps to retain moisture in the surface layer.

Management Implications

Grassed sites are unfavorable for the establishment of natural or artificial regeneration.

Soil moisture conditions under burned and scalped surfaces on all exposures studied are favorable for the survival of already established seedlings or planted stock throughout the growing season.

Moisture is likely to be inadequate for the germination and survival of new seedlings until after the summer rains begin.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 207

REST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Derivation of the 1- and 10-Hour Timelag Fuel Moisture Calculations for Fire-Danger Rating

Michael A. Fosberg and John E. Deeming[1]

Procedures for calculating the moisture contents of 1- and 10-hour timelag fuels have been developed based on theoretical calculations of the rate of moisture transport in wood. The 1-hour timelag calculation is superior to fine fuel moisture calculations developed previously because there is no regional bias, making it valid over a wider range of conditions, and because it separates out the effects of the environmental factors of temperature, humidity, and solar radiation. The 10-hour timelag calculation produced values reasonably consistent with observations obtained from 1/2-inch ponderosa pine fuel sticks exposed under field conditions.

KEY WORDS: Forest fuels, forest fire hazard, fuelwood.

Fuel moisture content is one of the major ariables in evaluating fire danger and prelicting fire behavior. Rothermel's[2] developnent of a mathematical model for predicting ire spread in a heterogeneous fuel and its ubsequent adaptation to fire-danger rating reuire moisture inputs for more than one class f fuel. Dead fuels have been classified by heir moisture timelag for fire-danger rating.[3] hese fuel classes are the 1-, 10-, and 100-hour lasses, which correspond roughly to cylindrical fuels less than 1/4 inch in diameter, 1/4 to 1 inch, and 1 to 3 inches in diameter, respectively.

In the past, these fuels have been represented by physical analogs; basswood slats for fine or 1-hour timelag fuels, half-inch ponderosa pine fuel sticks for the intermediate or 10-hour timelag fuels, and 2-inch ponderosa pine dowels for the heavier 100-hour timelag fuels (Gis-

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[1] *Authors are, respectively, Principal Meterologist and Research Forester, National Fire-onger Rating Project, U. S. Forest Service, Rocky ountain Forest and Range Experiment Station, ort Collins, Colorado.*

[2] *Rothermel, R. C. A mathematical model for fire spread predictions in wildland fuels. 1971. (Unpublished report on file at N. Forest Fire Lab., U. S. Dep. Agr., Forest Serv., Missoula, Mont.)*

[3] *Fosberg, Michael A., James W. Lancaster and Mark J. Schroeder. Dead forest fuels characterization by moisture timelag. (Manuscript in preparation.)*

borne 1936). A computational system is needed, however, because field use of physical analogs is not always feasible, and direct measurements are seldom available when analyzing records for fire-danger ratings. Past work has produced two schemes for estimating the moisture contents of fuels in the 1-hour group. One consists of regression equations based on field measurements of basswood slats (Storey 1965),[4] the other consists of a weighted average of the equilibrium moisture value for wood corresponding to the ambient dry bulb temperature and humidity, and the observed moisture content of a half-inch ponderosa pine fuel stick.[5] In general, computational schemes have not been used operationally to represent the 10-hour timelag fuel moisture, although one has been developed (Storey 1965). The 100-hour timelag fuel has generally been represented by a buildup index in some form. Fosberg (1971) developed a direct computational scheme for this fuel.

Previously developed computational systems were generally not well suited for universal application because the derived relationships were based on limited ranges of environmental conditions characteristic of specific geographic areas. Thus, for nationwide application, the resultant regression equations had to be extrapolated beyond the ranges of data. This limitation is overcome by use of the general solution developed by Fosberg et al. (1970) and Fosberg (1971).

The General Theory

The basic theoretical solution for moisture gain and loss is

$$\frac{\delta m}{\Delta m} = 1-\zeta e^{-\lambda t} \tag{1}$$

where the relationship between change in moisture content, $\delta m = m_{i+1} - m_i$, and the difference between the surface moisture content and the initial moisture content, $\Delta m = mb_{i+1} - m_i$, is a simple exponential function. In this expressio, m_{i+1} is the moisture content at the end the change period, $i+1$, m_i is the moisture co tent at the beginning, and mb_{i+1} is the mo ture content of the surface fibers at the en ζ is the similarity coefficient, λ is the i verse of the timelag, and t is the time perio over which the moisture exchange takes plac The similarity coefficient is dependent on th product λt. ζ is derived empirically and used to insure the value of $\delta m/\Delta m$ which is co sidered a nondimensional constant. Stab solutions exist only over the interv $.05 < \lambda t \leq 0$ 0.5. This implies that, for 1-hou timelag fuels, the moisture contents may b predicted for periods of one-half hour or les Since we are interested in predictions for muc longer periods, these short-period predictio must be assembled sequentially. To do th we solve equation (1) for the moisture conte at the end of a time step $i+1$. δt is tl length of the time step; $t = i\delta t$.

$$\delta m = \Delta m(1-\zeta e^{-\lambda\delta t})$$

$$m_{i+1} - m_i = (1-\zeta e^{-\lambda\delta t})(mb_{i+1} - m$$

$$m = (1-\zeta e^{-\lambda\delta t})(mb_{i+1} - m_i) + m_i$$

For notational convenience, let $\chi = 1-\zeta e^{-\lambda\delta t}$, th

$$m_{i+1} = \chi(mb_{i+1} - m_i) + m_i$$

$$m_{i+1} = \chi mb_{i+1} + m_i\,(1-\chi)$$

To solve for the moisture content after number of time steps, $i+0, 1, 2, --, n-1,$ r

$$m_1 = \chi mb_i + m_o(1-\chi)$$

and

$$\begin{aligned} m_2 &= \chi mb_2 + m_1(1-\chi) \\ &\vdots \\ m_{n-1} &= \chi mb_{n-1} + m_{n-2}(1-\chi) \\ m_n &= \chi mb_n + m_{n-1}(1-\chi) \end{aligned}$$

where the initial value for each subseque step is the final moisture content from th previous computation. These individual sol tions may be combined to give a solution the general form:

$$m_n = \chi[mb_n + \sum_{j=1}^{n-1}(1-\chi)^j mb_{n-j}] + (1-\chi)^n m_o$$

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[4] U. S. Forest Service. Washington Office, Division of Fire Control. Derivation of spread phase tables. National Fire-Danger Rating System. 54 p. 1966. (Unpublished report on file at Rocky Mt. Forest and Range Exp. Sta., U. S. Dep. Agr., Forest Serv., Fort Collins, Colo.)

[5] U. S. Forest Service. Wildland fire danger rating. n.d., n.p. Pac. Southwest Forest and Range Exp. Sta., Berkeley, Calif.

Where j is the interval of summation; $j=n-i$.

Equation (3) may be simplified by first considering that no precipitation occurs. This assumption may at first seem unduly restrictive, but the effect of precipitation can be added later.

Since drying conditions preceding the time for which the fuel moisture is to be evaluated are cyclic, a consideration of that variation must be incorporated in the computation. This is accomplished by defining and computing a climatological coefficient c_{n-j} which is the ratio of the equilibrium moisture content at the end of time step i, me_{n-j} and the equilibrium moisture content at the end of time step n, me_n

$$c_{n-j} = \frac{me_{n-j}}{me_n}$$

The moisture content at the immediate surface of the fuel element is governed by the environment and, for all practical purposes, is the equilibrium moisture content. Except when it is raining, m_b then can be set equal to m_e. Thus, equation (3) becomes

$$m_n = \chi[me_n + \sum_{j=1}^{n-1}(1-\chi)^j me_{n-j}] + (1-\chi)^n m_o$$

with

$$me_{n-j} = me_n \, c_{n-j}$$

$$m_n = \chi[me_n + me_n \sum_{j=1}^{n-1}(1-\chi)^j c_{n-j}] + (1-\chi)^n m_o$$

$$m_n = \chi me_n [1 + \sum_{j=1}^{j=n-1}(1-\chi)^j c_{n-j}] + (1-\chi)^n m_o \quad (4)$$

and the term $(1-\chi)^n \, m_o$ becomes very small and can be neglected. The precipitation effects are now added by going back to equation (1) and determining a moisture change, dmp, due to precipitation.

$$dmp_{i+1} = \chi mb_{i+1} + m_i(1-\chi)$$

This again must be solved in series. Thus wetting becomes

$$dmp_n = \chi \sum_{j=1}^{n-1} \delta_i (1-\chi)^j \, mb_{n-j} \quad (5)$$

where mb is the wetting boundary condition,[6] $mb = a+b \, t_{di}$ where t_{di} is the duration of the precipitation during time step i. The Kronecker delta,[7] δ_i, is "0" if there is no precipitation during the time step i and is "1" if there is precipitation. The dmp_n given by equation (5) is added to the m_n from equation (4) to give the total moisture content.

Application of the General Theory to Field Problems

The solutions provided by equations (4) and (5) may be obtained for the particular cases of the 1- and 10-hour timelag fuels. The solution is obtained by specifying the similarity coefficient, ζ, from laboratory studies, and the timelag, λ^{-1}, the time increment, δt, and the climatological coefficient, c_{n-j} for a 1430 LST observation. For the 1-hour timelag fuel, 12 time steps of ½-hour duration were used. Thus, $\zeta=1, \lambda=1, \delta t=0.5$, and the term $\chi=0.3935$. The climatological coefficients are averages computed from data taken during six general observation periods of the O'Neill, Nebraska, Great Plains Study (Lettau and Davidson 1957). The standard weather shelter temperature and humidity readings were converted to equilibrium moisture content (U. S. Forest Service 1955). These coefficients (fig. 1) could then be substituted into equation (4) to give the resultant equation

$$m = 1.0329 \, me \quad (6)$$

for a midafternoon observation.

Since the equilibrium moisture content depends only on temperature and humidity, a table readily usable in the field may be constructed (table 1). Since the temperature and humidity are measured in shelters 4½ feet above the ground, and the moisture content of the fuel depends on the temperature and humidity of the air immediately in contact with its surface, the shelter readings must be corrected to account for the temperature and moisture lapse rates between the levels of the instruments and the surface of the fuels on sunny

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[6] *A laboratory experiment showed a linear relationship between the wetting boundary conditions mb and the duration of wetting td. The constants a and b were empirically derived from these wetting experiments for both 1/2-inch and 2-inch ponderosa pine dowels.*

[7] *The Kronecker delta is a mathematical notation used to denote a situation where there are two or more possible conditions which are mutually exclusive, i.e., valid or nonvalid, existent or nonexistent. In this case it denotes rain r no rain.*

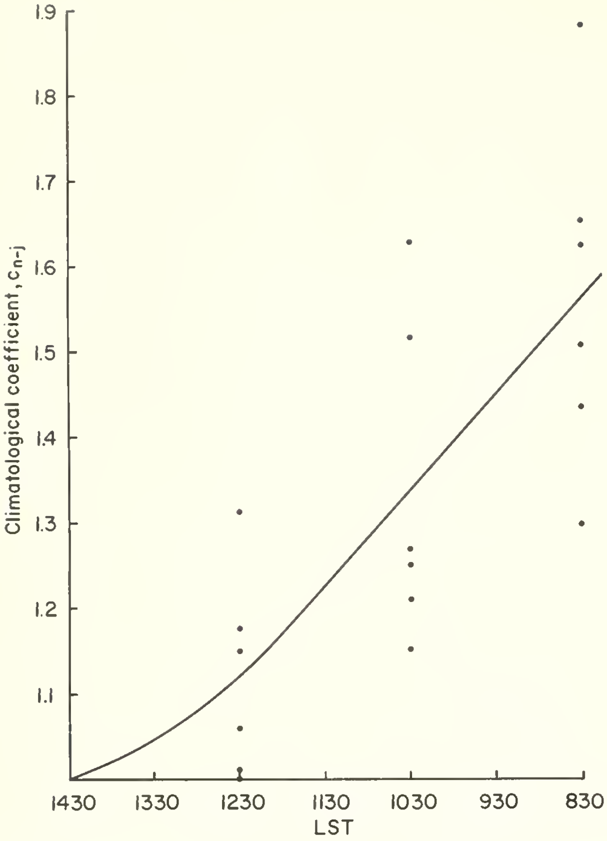

Figure 1.--The climatological coefficients, c_{n-i}, for a 1430 LST observation. The data points are the coefficients calculated from the bi-hourly observations for six observation periods of the O'Neill, Nebraska, Great Plains study (Lettau and Davidson 1957).

days. The temperature and moisture lapse rates depend on a number of variables not considered because of the complexity that would result. They are windspeed, aspect, slope, stability, and the radiation absorption and emission characteristics of the underlying surface. The averages of values found in the literature result in corrections of 15° F. increase in temperature and a 3° F. increase in dew point temperature (Geiger 1957). These yield an adjusted relative humidity which is 75 percent of the shelter value.

Increases in moisture content due to precipitation are difficult to compute for the 1-hour timelag fuel because, first, precipitation duration must be known to the nearest half-hour, and, second, the duration must be applied to the particular time steps in which it occurred. The second difficulty is the most restrictive because it would require solution of the series or a very large number of tables to provide for all contingencies. Neither of these are practical. A straightforward alternative is to assume that, when it is raining, the fuels are at fiber saturation or 30 percent moisture content.

Calculation of the 10-hour timelag fuel moisture followed the same procedures except that six 4-hour time steps were used. Thus $\delta t=4$, $\lambda=0.1$, and $\zeta=.98$, giving a value of $\chi=.343$. The climatological coefficients were determined from the same source and in the same manner as for the 1-hour timelag fuels. This gives

Table 1.--One-hour timelag fuel moisture (percent)

	State of weather[1]		Relative humidity (percent)																				
	Code 0-1 Temperature	Code 2-9 Temperature	0 ↓ 4	5 ↓ 9	10 ↓ 14	15 ↓ 19	20 ↓ 24	25 ↓ 29	30 ↓ 34	35 ↓ 39	40 ↓ 44	45 ↓ 49	50 ↓ 54	55 ↓ 59	60 ↓ 64	65 ↓ 69	70 ↓ 74	75 ↓ 79	80 ↓ 84	85 ↓ 89	90 ↓ 94	95 ↓ 99	1
SUNNY	10→29		1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	
	30→49		1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	
	50→69		1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	
	70→89		1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	
	90→109		1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	
	109+		1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	
CLOUDY		10→29	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	+
		30→49	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	+
		50→69	1	2	3	4	5	6	6	8	8	9	10	11	11	12	14	16	17	20	23	25+	+
		70→89	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	+
		90→109	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25	+
		109+	1	2	2	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	+

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[1] In recording fire-weather observational data, the "state of weather" code 0 indicates a clear sky and 1 indicates 5/1 or less cloud cover; both are in the general condition "Sunny." 2 through 9 indicate more than 5/10s cloud cover and various conditions of precipitation, generally included here under "cloudy."

prediction equation for the moisture content of the 10-hour timelag fuels of

$$m = 1.2815\ me \tag{7}$$

for a midafternoon observation. As with the 1-hour timelag fuel, shelter readings were corrected to account for temperature and humidity profiles on sunny days.

The effect of precipitation on the 10-hour timelag fuel was determined by considering precipitation durations of 1 to 4 hours in each of the six periods beginning at the time of the observation used to rate the day, usually in the early afternoon. These increases in moisture content were sufficiently stable to allow the 24-hour period from one observation to the next to be split into a first 16-hour period and a final 8-hour period, which is much more practical for field use where accurate rainfall occurrence records are not easily attainable. The table for field use (table 2) is similar in format to that used to calculate the 1-hour timelag fuel moisture. If precipitation occurs, part B of the table is used, and the correction for precipitation is added to the results derived from part A.

Certain errors result when the computations are made with data from the tables generated for field use. The final term in equation (4) is not always negligible for the 10-hour timelag fuel. The error made in neglecting this term becomes noticeable only when the moisture content is well above fiber saturation, a situation that is not important in fire-danger rating, however, since fuels with moisture contents above this value can be considered, for all practical purposes, to be fireproof. Breaking the day

Table 2.--Ten-hour timelag fuel moisture (percent)

Part A[1]

State of weather			Relative humidity (percent)																				
	Code 0-1 emperature	Code 2-9 Temperature	0→4	5→9	10→14	15→19	20→24	25→29	30→34	35→39	40→44	45→49	50→54	55→59	60→64	65→69	70→74	75→79	80→84	85→89	90→94	95→99	100
SUNNY	10→29		1	2	4	5	6	6	7	8	9	9	10	11	12	13	14	14	15	16	17	18	20
	30→49		1	2	3	5	6	6	7	8	9	9	10	11	12	12	13	14	15	16	17	18	20
	50→69		1	2	3	4	5	6	7	8	8	9	10	11	11	12	13	13	14	15	16	17	19
	70→89		1	1	3	4	5	5	6	7	8	8	9	10	11	12	12	13	14	14	16	16	18
	90→109		1	1	3	4	4	5	6	7	8	8	9	10	11	11	12	12	13	13	15	16	18
	109+		1	1	3	3	4	5	6	7	7	8	9	10	10	11	11	12	13	13	15	15	17
CLOUDY		10→29	1	2	5	6	7	8	9	10	11	12	13	14	15	17	18	20	23	25+	25+	25+	25+
		30→49	1	2	5	6	7	8	9	10	11	12	13	14	15	16	18	20	23	25	25+	25+	25+
		50→69	1	2	4	5	6	7	8	9	10	11	13	13	14	16	17	19	22	24	25+	25+	25+
		70→89	1	2	4	5	6	7	8	9	10	11	12	13	14	15	16	18	21	24	25+	25+	25+
		90→109	1	2	3	4	5	7	8	9	10	11	11	12	13	14	16	18	20	23	25+	25+	25+
		109+	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	20	22	25	25+	25+

Part B[2]

Time precipitation occurred	Precipitation duration (hours)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Basic observation yesterday to 0600 today	2	4	7	9	11	14	16	18	20	23	25	25+	25+	25+	25+	25+
0600 today to basic observation today	7	15	22	25+	25+	25+	25+	25+	--	--	--	--	--	--	--	--

[1] If no precipitation has occurred since basic observation time yesterday, today's 10-hour timelag fuel moisture is read irectly from this part of the table.

[2] When precipitation occurs, add the results from this part of the table to the results of part A. The sum is today's)-hour timelag fuel moisture value.

into 16-hour and 8-hour periods instead of six 4-hour periods for computing the contributions of rain to the 10-hour timelag fuel moisture accounts for much of the error in this computation. The reason is that the magnitude of the precipitation contribution to the final answer is highly dependent on when the precipitation occurs. The error is such that short-period rainfall effects are overestimated if they occur 16 hours or longer before the observation, and are underestimated if they occur within 4 hours of observation time.

Evaluation and Comparison of the Prediction

The 1-hour timelag fuel moisture predictions have not been compared to field data. Instead, they are compared to the fine fuel moisture calculations used in the wildland fire-danger syster used in California and to the fine fuel moisture calculations developed by Storey (1965) and use in the 1964 version of the National Fire-Dange Rating System. These comparisons (fig. 2 show that predictions developed here compar well with both in general, but that under condi

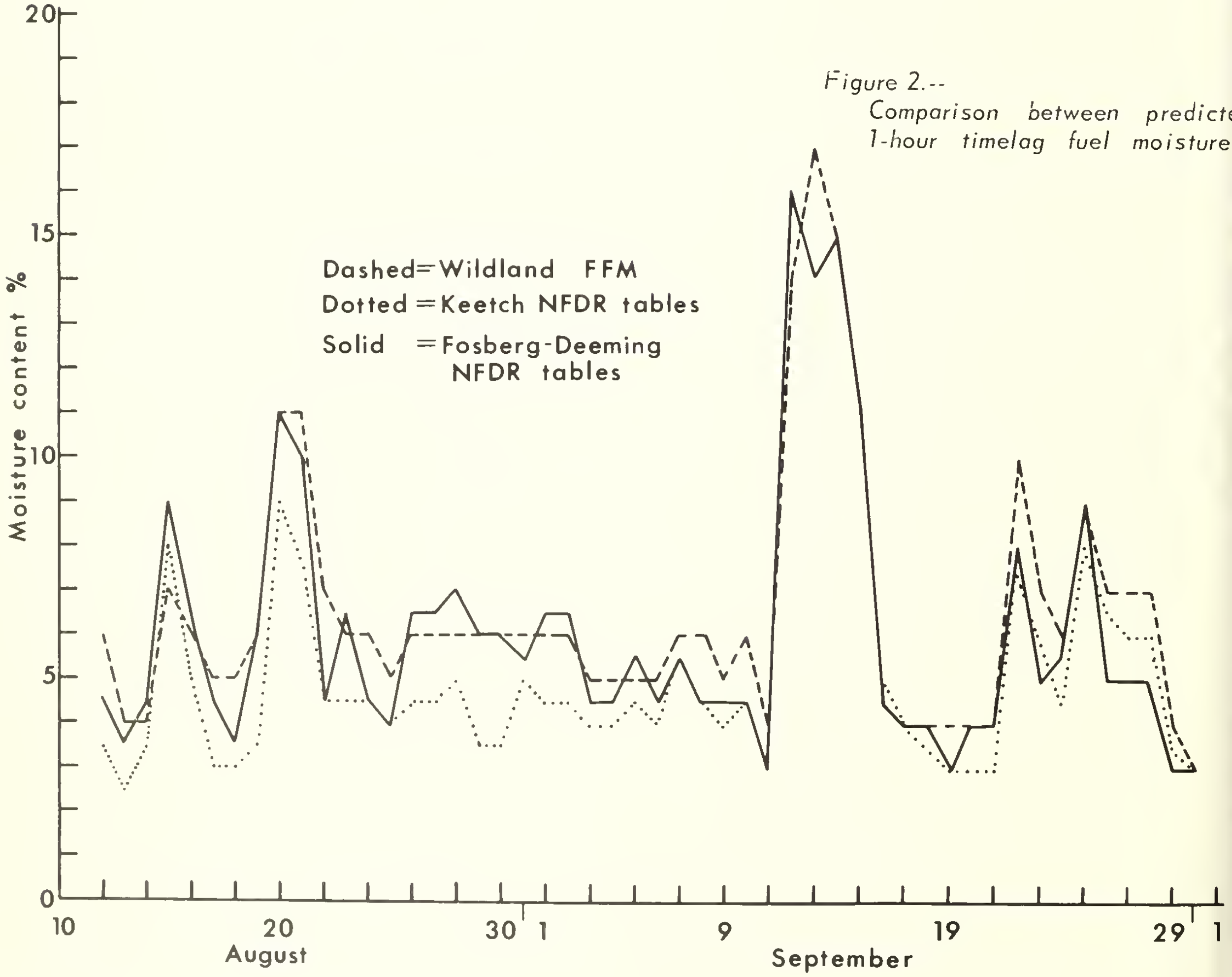
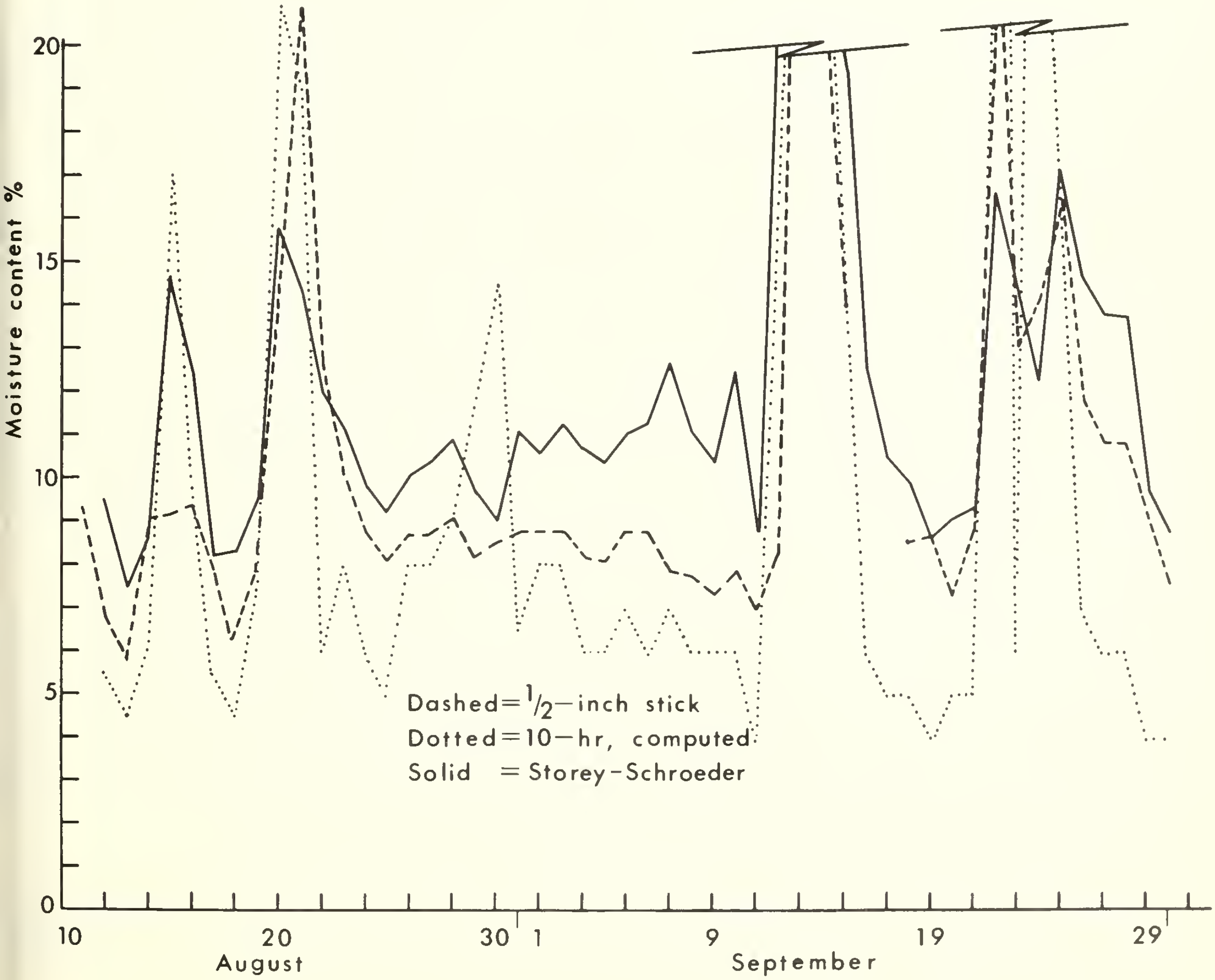


Figure 2.--Comparison between predicted 1-hour timelag fuel moistures.

tions of low relative humidity, they are more nearly like the wildland system and that under periods of high humidity, they are more like the equations developed by Storey. This is a desirable feature, since the wildland system was developed from data taken in arid regions and the equations developed by Storey are based on data collected in humid regions.

The 10-hour timelag fuel moisture calculations were compared directly with the half-inch stick observations and with Storey's prediction equation as modified by Schroeder (1969) (fig. 3). Comparison with the Storey-Schroeder equation shows reasonable agreement except after periods of precipitation. This is to be expected since the Storey-Schroeder equation does not consider precipitation duration. Comparison with the observed half-inch stick moisture contents is also reasonable provided one considers (1) the limitations introduced by the assumptions made in predicting the contribution of precipitation, and (2) the fact that the half-inch sticks have timelags varying from 12 to 15 hours.[8]

Figure 3.--Comparison between predicted and observed 10-hour timelag fuel moistures.



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[8] Personal communication with William Fischer, Northern Forest Fire Laboratory, Missoula, Montana.

Summary

Prediction equations for the 1- and 10-hour timelag fuel moistures based on diffusion theory show good agreement with existing methods of computing these values. To insure computational stability, the prediction consists of solving the equations for short time periods and assembling these solutions into a final answer. The 1-hour timelag fuel moisture prediction equation uses 12 steps of 1/2 hour each; the 10-hour uses six steps of 4 hours each.

For the derivation of the tables used in the National Fire-Danger Rating System now being introduced, a diurnal cycle of temperature and humidity characteristic of continental climates was used. A principal advantage of this prediction approach is that tables can be derived specifically for areas which have a radically different diurnal weather cycle—areas which are subjected to marine air incursions, for example. This flexibility stands in sharp contrast to existing systems which exhibit strong bias toward the climatic regions in which they were developed.

The computed 1-hour timelag fuel moisture values compare well under conditions of low humidities with those derived from the California wildland system, and under high humidity conditions with those derived from the 1964 version of the National Fire-Danger Rating System.

The computed 10-hour timelag fuel moisture values compare well with field data taken from 1/2-inch ponderosa pine fuel moisture sticks.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 208

REST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Rearing and Training Deer for Food Habits Studies

Donald W. Reichert[1]

Wild does are trapped in winter and held until after fawning. Fawns are left with the doe at least 12 hours to assure feeding of colostrum, but less than 24 hours to prevent development of wildness. Reliance on the human trainer develops through bottle feeding and frequent contact. Initial training for field use requires 4 to 6 weeks, but continuous rehearsal is necessary.

Keywords: Odocoileus hemionus hemionus, deer, wildlife management, forest-game management relations.

The study of food habits is a major research activity in wildlife ecology. Most of the work in this field has involved analysis of stomach contents or feces, or observation of wild animals. But in an effort to acquire more exact information about specific habitats, many workers have used tame animals—for example, Dzieciolowski (1966) observed tame red deer, Bergerud and Nolan (1970) caribou, Wallmo (1951) and Hoover (1971) pronghorn antelope. Healy (1967), McMahan (1964), Wallmo and Neff (1968), and Watts (1964) discussed the use of deer (Odocoileus spp.) for such purposes.

This Note reviews the methods we have used to rear and train Rocky Mountain mule deer (O. hemionus hemionus) for use in food habits studies and grazing experiments.

Acquisition and Initial Handling of Fawns

Over a period of 5 years we have obtained newborn fawns that were captured in the wild, born in pens from wild does trapped the preceding winter, or born of does that were raised in pens. We have found no differences in the adaptability of fawns from these sources. We learned early, however, that fawns left with their mothers more than 2 or 3 days, whether in the woods or in pens, usually are too wild to train. Yet, if we take fawns from penned does as soon as they are cleaned and able to stand, we have high incidence of sickness and mortality. Best results are obtained if the fawn is left with its dam for at least 12 hours but less than 24 hours. This permits the fawn to suckle and obtain colostrum, but exposes it to the surrogate mother (trainer and bottle) before fear of humans is imprinted.

Most of our fawns have been born late at night or early in the morning. As soon after birth as possible, usually within 3 to 6 hours, tincture of iodine is applied to the navel to prevent infection. During the first day the fawns are closely observed to assure that they are being nursed. If they are rejected or unable to nurse, they are taken immediately and bottle fed. While we have fed cow colostrum to sucking fawns, we have more confidence in natural colostrum. Doe's milk contains colostrum at a relatively high level and is rich in vitamin A for 3 days (Youatt et al. 1965). After 12 hours, however, antibodies of colostrum are no longer beneficial to the nursing fawn (personal communication, Dr. David Varra, Veterinary Science Department, Colorado State University).

In our first attempts, the parturient does were in pens at Fort Collins, Colorado, and the fawns were raised in a residential back yard. Because of high incidence of disease and mortality, we subsequently trapped wild does in winter and placed them in a pen constructed on nearby winter range. As the fawns were born they were removed to pens on

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[1] *Range Research Technician, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

summer range at the Fraser Experimental Forest. Several pens of 4-foot-high snowfence, each about 50 by 50 feet in size, were constructed so that two to four fawns could be kept in each with a distance of 20 to 30 feet between pens to minimize possible contagion. These pens are in a forest stand and contain a variety of natural forages. We have had very little disease and no mortality at this site. However, during 1971, our cooperators in the Department of Fishery and Wildlife Biology, Colorado State University, have also had considerable success with fawns born and raised in pens at Fort Collins.

Feeding

There is some published information on the composition of deer milk (Kitts et al. 1956 for black-tailed deer, Odocoileus hemionus columbianus; Silver 1961, and Youatt et al. 1965 for white-tailed deer, Odocoileus virginianus). However, feeding formulas recommended in these and other reports (Aldredge 1971, Murphy 1960, Trainer 1962, Long et al. 1961) are so contradictory they are not helpful. Likewise, the successes and failures of others with whom we have had personal contact have little in common.

We have tried a variety of formulas, and have had best results with one made up of five parts evaporated canned milk and three parts water. We add 0.3 cc. of pediatric vitamins to two feedings each day to provide adequate vitamins A and C. Quantities per feeding and feeding schedules are shown in figure 1. Eight-ounce plastic baby bottles are used; filled to capacity they hold 10 ounces. Because fawns are voracious nursers (fig. 2), the nipple holes are slightly enlarged to accommodate their appetite. All milk utensils are washed and sterilized in boiling water prior to each feeding.

We consider "tender loving care" (fig. 2) to be an essential element throughout the rearing period. At each feeding, the trainer takes extra time to bestow some affection on each fawn.

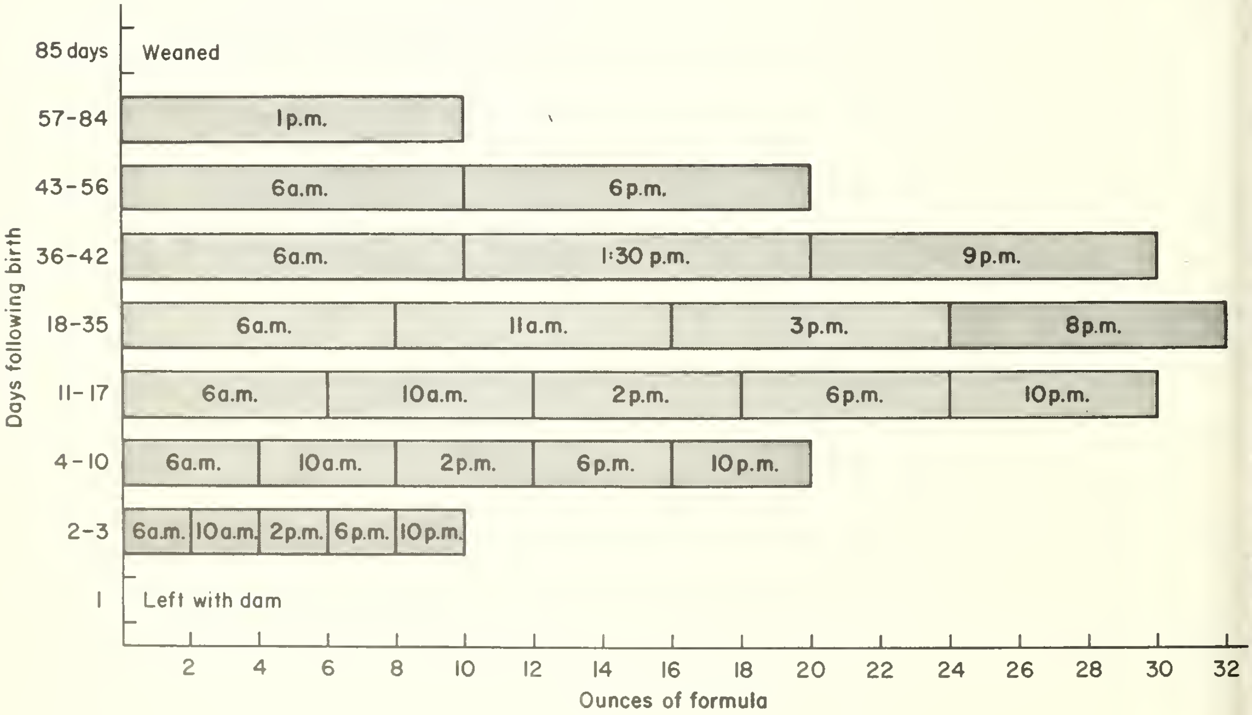

Figure 1.--Daily time schedule and cumulative amount of special formula bottle-fed to each fawn from second day following birth until weaned. Formula was five parts evaporated canned milk, three parts water; 0.33 cc. of pediatric vitamins added to two feedings each day.

Figure 2.--Trainer fondles each fawn at each feeding to tame and train it for field use. (Photos courtesy of Colorado Game, Fish and Parks Div.)

At about 2 weeks of age the fawns begin to graze natural forage available in their pens. At this time a bucket of water is placed in each pen. At 1 month a small amount of commercial lamb creep feed is placed in each pen; the amount is gradually increased until it is available ad libitum. At 2 months the creep feed is mixed 50/50 with a specially made ration consisting of ground chopped corn, barley, milo, and bran. Molasses and Purina[2] special protein supplements are also added. Protein content of this ration is 20 percent. From 2 to 3 months the proportion of creep feed is reduced and finally eliminated. Alfalfa hay is introduced at about 1 month.

Sickness

Dietary upsets and bacterial infections resulting in diarrhea are the only common sicknesses we have encountered. Kramer et al. (1971) reported three strains of Escherichia coli as causing high mortality in our fawns in 1969. Salmonella and Clostridium were isolated from some of our fawns in 1968. Salmonella has been reported as a common pathogen in white-tailed deer fawns (Cook et al. 1971, Debbie 1968, Robinson and Marburger 1970).

Diagnosis and proper treatment of fawns with these bacterial infections have not yet been resolved, nor do we have conclusive recommendations for the recognition and treatment of diarrhea caused by improper diet. However, we have developed a number of lay practices. The fawns are closely observed to insure early recognition of digestive upset or infection. At each feeding, the anal and rump areas of animals with diarrhea are cleaned with a wet sponge and dry napkin, primarily to minimize fly contact. Pens are cleaned of droppings at least once a day. If possible, sick animals are transferred to a separate pen. When we see an apparent dietary problem, one teaspoon of Corrective Mixture, a product of Massengill Co., is added to the milk twice daily. Neomix Plus, a product of the Upjohn Co., also appears to be effective for diarrhea control.

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[2] *Trade names and company names are used for the benefit of the reader and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

Training for Field Use

Our training program has five major objectives:

1. To establish the deer's confidence in and reliance on the trainer.
2. To teach the deer to follow the trainer, an aptitude which comes somewhat naturally from the first.
3. To teach the deer to accept the placement and removal of a harness.
4. To train the deer to accept leading with a rope attached to the harness.
5. To train the deer to load in and out of, and ride in, the truck used for transportation to study area.

The first objective is accomplished by acquiring the fawn at an early age, by the feeding program, and by frequent empathetic contact throughout the deer's life. Empathy is important, but you either have it or you do not, and not much more can be said about it. In order for the deer to become adequately imprinted, it is imperative that one and not more than two people be responsible for all the rearing and training work. However, a general requirement applicable throughout is that all activities around the deer be conducted as slowly, patiently, and quietly as possible.

At 10 to 14 days of age, fawns are let out of the pen to follow the trainer on walks in the field. At this age, the fawn's attachment to the trainer should be comparable to that of a normal fawn to its mother.

Harness training begins at the same time. Healy (1967) and Neff (1967) describe deer harnesses from which our present model evolved. Two 1/8- by 1-inch nylon straps, one around the base of the neck and the other around the body just behind the shoulders, are connected dorsally by a third strap sewed to the neckpiece and connected by a snap to a ring on the body piece (fig. 3). Five to six harnesses of increasing size are needed to accommodate the deer from age 2 weeks to 2 years, after which growth is negligible.

While Neff (personal communication) saw advantages in a ventral connection of the harness pieces and leashing at the brisket, we have found the dorsal connection and leashing from above the shoulder to provide better control.

Initially only the neckpiece is used on the fawn until it is obvious that the entire harness would be accepted without fear. The harness is then put on and removed several times each day until this has become a familiar routine. Deer are never left harnessed and unattended because of the chances of strangulation. Leading is a crucial phase of training, both for the

Figure 3.--Harness training begins when fawn is 10 to 14 days old. Two-piece harness and leash are used to teach the tamed deer to lead.

deer and the handler. The deer must learn to accept some restraint, but is inherently capable of tolerating only a limited amount. We use a 12-foot, 3/8-inch soft nylon rope for a leash. The rope is usually held 1 to 2 feet from the harness, at most 3 feet, and the additional length is used solely for emergency situations. This position permits gentle guidance in any direction, provides the opportunity to release tension quickly without losing control, and minimizes the chance of the rope entangling the deer. The dorsal attachment of the leash results in a lifting pressure on the chest which the deer seem to accept without panicking. Very little tension is felt around the neck, which appears to be important. A gentle push on the rump helps guide the deer forward or to either side (fig. 4).

Training to load, ride, and unload is begun at about 10 days by enticing two fawns at a time into the truck at feeding periods with the nursing bottle. After being fed, petted, and played with in the truck on several occasions they lose their fear of the truck. They are then taken on short rides to get them accustomed to the movement of the vehicle and learn that the experience ends without harm.

A truck with a closed canopy, such as our custom-built unit, is imperative (fig. 4).

Figure 4.--Tamed deer willingly leave and return to the canopy-covered utility-bed pickup truck used to transport them to and from the study area.

Next, the deer are taken in pairs on simulated field trials. They are harnessed, led to the truck with leash attached, loaded and driven to an unfamiliar location where they are released and allowed to wander and graze at will for 1/2 to 1 hour. During this period the leash is not used. The trainer then trots or walks at a fast pace back to the truck. If the early conditioning has been successful, the deer willingly follow the trainer to the truck where the leash is attached to facilitate loading. Many deer leap in the truck before the leash is attached.

This field training procedure is rehearsed at least once a day with each deer over a period of 4 to 6 weeks. The total training program is completed within 2 months. It must be rehearsed routinely, however, at least once and preferably twice a week throughout the deer's life to maintain an acceptable level of compliance. While we have maintained trained deer only to 2 years of age, D. J. Neff (personal communication) has used tame deer up to 5 years of age.

Some deer have an inherent wildness and never become tractable enough for use. At about 2 months of age these deer can be recognized and eliminated. Males will become intractable at yearling age if not castrated. We castrate with an elastrator and bands at about 3 months.

Deer remain in the handler's control in the field primarily because they do not like to be separated from their human companion. If the handler follows a deer, it will choose its own route and rate of travel (fig. 5). If the handler walks away—for example, to another study or back to the truck—the deer will follow. Low bleating sounds, with which the deer have been acquainted from birth, tend to reassure them and persuade them to follow.

Of 22 deer that we have raised and trained for this work, only two—which we feel were inherently unsuited—failed to adapt to our needs.

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Figure 5.--Trainer observes and tape records food habits of tamed deer. (Photo below courtesy of Colorado Game, Fish and Parks Div.)

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U S D A FOREST SERVICE
RESEARCH NOTE RM-209

REST SERVICE
DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Development of Siberian and Dahurian Larches After 10 Years in North Dakota

Richard A. Cunningham[1]

A 10-year test of trees grown in North Dakota from three Siberian larch, one Dahurian larch, and two hybrid larch seed sources indicated that trees from two Siberian origins may be suitable for windbreak plantings in the northern Great Plains.

Keywords: Larix sibirica, provenance test, shelterbelt plantings.

Siberian larch (Larix sibirica Ledeb.) has ot been planted extensively in Northern Great lains windbreaks, although limited trials inicated it may be well suited for windbreak lantings.[2] Potentially a large tree, Siberian rch could be used as the tallest member of a ultiple-row shelterbelt. In trials at Indian ead, Saskatchewan, block plantings of Siberian rch attained 66 feet in height and 9.1 inches iameter at breast height 56 years after planting.[3]

Limited trials with Dahurian larch (Larix melini (Rupr.) Litvin.) have indicated the rigins tested were not suitable sources of eed for planting in North Dakota.[2]

Siberian and Dahurian larch also have coniderable ornamental value as a result of their eciduous growth habit, unique among the onifers. Their seasonal change of foliage rom a pale green in the spring to a pastel yellow in the autumn makes them highly desirable where esthetic appeal is of high priority.

To investigate further the potential of Siberian and Dahurian larches for windbreaks, the Lake States (now North Central) Forest Experiment Station initiated a seed source study in 1961.

Methods

Seeds of Larix sibirica, L. gmelini, and L. sibirica x gmelini, representing six different origins, were collected in 1954-56 in the U.S.S.R. (fig. 1). They were sown in the spring of 1957 in the Hugo Sauer Nursery of the USDA Forest Service, near Rhinelander, Wisconsin (table 1).

The stock was lifted as 2-2 transplants in the spring of 1961 and shipped to the Denbigh Experimental Forest, North Dakota, for field planting. The trees were planted at a spacing of 14 by 14 feet in square 4-tree plots replicated 10 times in a random complete-block design. White spruce (Picea glauca (Moench) Voss) 2-2 transplants (Black Hills seed source) were interplanted as fillers to reduce the overall spacing to 7 by 7 feet. The soil was a deep loamy sand with a depth to water table of approximately 10 feet. The ground cover of native grass was plowed and disked in the year prior to planting, and was disked again immediately before planting.

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[2] *George, Ernest. Tree and shrub species for the orthern Great Plains. U.S. Dep. Agric. Circ. 912, 46 p. 953.*

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Table 1.--Origins of larch seed collections

Seed source number	*Larix* species	Locality of origin	North latitude	East longitude
656	*gmelini*	Amurskaya Province, Mazonovski Dist., Mazonovski Forest; elev. 200 m.	51°31'	129°
658	*sibirica*	Tuvinskaya Autonomous Prov., Barun.-Khemchikski Dist.	51°	92°
659	*sibirica*	Altaiskaya Mountain Autonomous Prov., Upper Katunski Forest; elev. 1600 m.	50°	86°
660	*sibirica*	Altaiskaya Mountain Autonomous Prov., Upper Katunski Forest; elev. 1300 m.	50°	86°
662	*sibirica* x *gmelini*	Sverdlovskaya Prov., Sinyachikhinski Dist., Trans-Urals; elev. 150 m.	58°	62°
663	*sibirica* x *gmelini*	Arkhangelskaya Prov., Upper Toemski Dist., Vyiski Forest	62°	46°

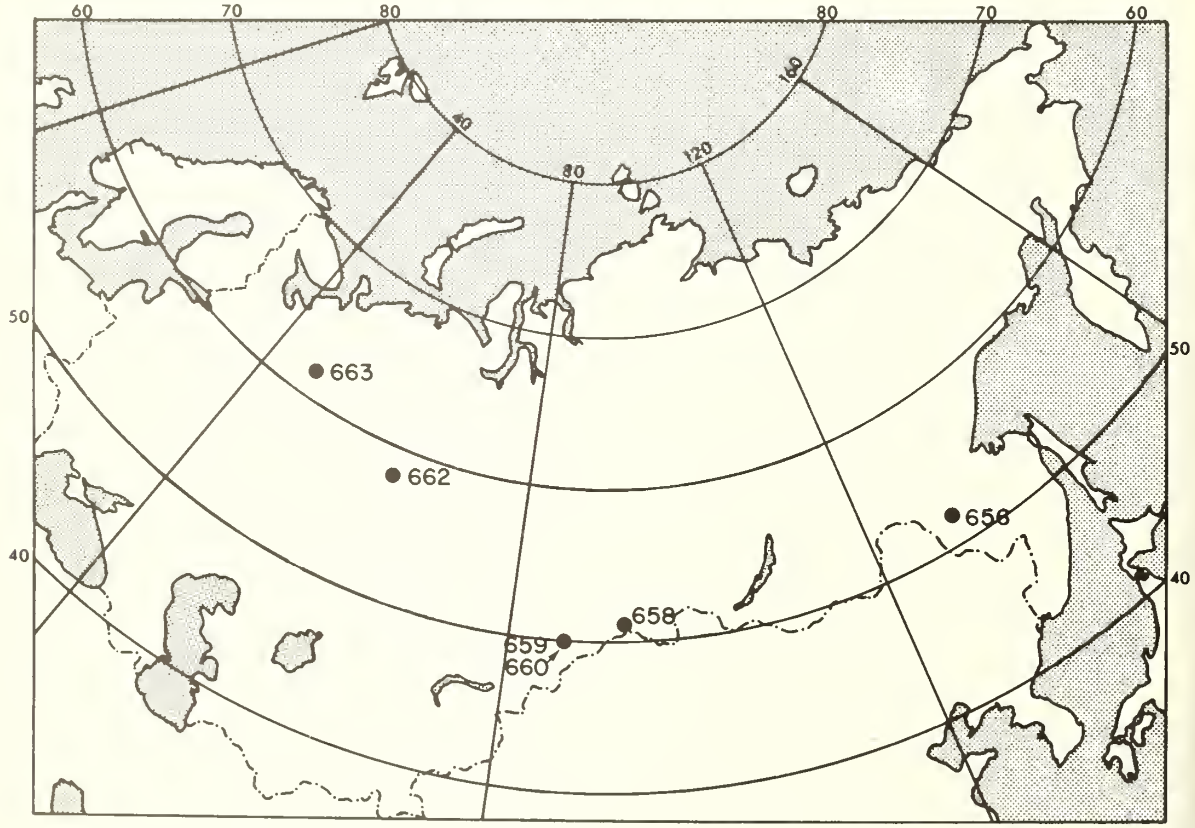

Figure 1.--Locations in U.S.S.R. of the six origins of Larix seed.

The planting stock had broken dormancy before it was lifted from the nursery in Wisconsin. Terminal and lateral buds had swollen and new foliage had appeared.

Weather conditions at the time the trees were planted were nearly ideal, but drought conditions prevailed throughout most of the growing season in 1961. The effects of this drought, combined with those due to early flushing, resulted in poor survival the first year. Replanting in 1962 and 1963 replaced some of the early losses, but there was insufficient planting stock to replace them all. Damage and losses from deer browsing and rubbing have also reduced the growth and survival of trees in the plantation.

Results

Survival

Trees of the *Larix gmelini* source and of one *L. sibirica* x *gmelini* hybrid source survived very poorly and were each represented by only one remaining tree (table 2). Survival of trees from the other hybrid seed source averaged 20.0 percent. Trees of the *Larix sibirica* seed sources from Tuvinskaya Province (658) and from Altaiskaya Mountain Province (659) survived moderately well. Trees of another seed source from a slightly lower elevation in Altaiskaya Mountain Province (660) suffered high mortality. Such survival differences among trees from narrowly separated origins emphasizes the importance of choosing a suitable seed source from a relatively limited geographic area.

Growth

Only three of the six origins were represented by sufficient numbers of trees to be included in an analysis of variance of total height and leader growth (table 2).

Differences among seed source means for total height and leader growth were not significant. Trees of *Larix sibirica* from the Tuvinskaya Province averaged the tallest and produced the most leader growth. Trees from the other two origins ranked nearly the same.

Table 2.--Percent survival and mean growth of two larch species and their naturally occurring hybrid 10 years after planting on Denbigh Experimental Forest, North Dakota

Seed source number	Number planted including replants	Survival	Growth: Total height	Growth: Leader (1970)
		Percent	Feet	Feet
659	65	1/42.2 a	6.9	1.6
658	79	33.0 ab	7.9	2.2
662	68	20.0 bc	7.1	1.5
660	40	7.5 cd	(2/)	(2/)
663	40	2.5 cd	(2/)	(2/)
656	80	1.1 d	(2/)	(2/)

1/ Numbers followed by the same letter suffix (a, b, c, or d) do not differ significantly at the 5 percent level (Duncan's multiple range test).

2/ Insufficient survival to provide meaningful values.

Conclusions and Recommendations

Although the overall survival of the plantation was poor (17.7 percent), trees from two of the Larix sibirica origins survived adequately and can be considered suitable sources of future seed supplies for windbreak plantings of this species in the Northern Great Plains. Trees from the Larix gmelini and L. sibirica x gmelini origins survived very poorly and cannot be recommended, on the basis of this test, for further use in this region.

Total heights after 10 years in the field are unimpressive, but the averages for current growth are encouraging. The average height growth of 1.5 to 2.2 feet likely represents a minimal estimate of the growth potential of Larix sibirica. Many of the trees measured had been heavily damaged by deer for several years in succession. Such damage not only reduced measurable current-year growth, but more importantly, reduced the tree's vigor and subsequently its growth the following year. Some trees with terminal leaders above the deer browse-line put on spectacular growth. One individual from source 658 grew 4.49 feet in 1970. Preferential browsing by deer among seed sources was not evident.

The results reported here are based on only a limited number of seed origins. The difficulty in procuring a representative sample of seed sources from the natural range of Larix sibirica makes it nearly impossible to conduct a comprehensive provenance study of the species. Problems in identifying the precise origin of seeds introduced earlier into the United States and Canada further complicate attempts to study variation in Larix sibirica.

Some of the trees in this study have begun to produce cones. Attempts will be made to locate as many other origins of Larix sibirica as possible for inclusion in a breeding program designed to improve the suitability of this promising species for windbreak planting in the Northern Great Plains.

Agriculture—CSU, Ft. Collins

U S D A FOREST SERVICE
RESEARCH NOTE RM-210

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S DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Throughfall and Stemflow Relationships in Second-Growth Ponderosa Pine in the Black Hills

Howard K. Orr[1]

In linear regression, gross rainfall alone accounted for 85 percent to as high as 99 percent of throughfall variation at individual gage points. Stemflow was also primarily dependent on gross rainfall. Results further demonstrate adjustment of throughfall for mean canopy density, adjustment of stemflow for tree size (d.b.h.), and combination of these relationships to estimate net rainfall for different stand densities.

Keywords: Watershed management, hydrology, Pinus ponderosa.

Variabilities of throughfall and stemflow have been variously attributed to random error (Stout and McMahon 1961), tree parameters, or characteristics of the forest canopy. In their extensive review of interception studies in mature hardwoods, Helvey and Patric (1965a) concluded there is no consistent evidence that interception losses are greatly affected by a variety of canopy densities. They go on to say, however, that failure to show variations in throughfall has probably been due more to failure of sampling methods to adequately measure variation than to lack of variation itself. They further maintain that throughfall under mature hardwoods must be inversely proportional to canopy density. The same logic must also apply to conifers.

Stout and McMahon (1961) conclude that amount of throughfall under a specific tree may vary with position or direction of the sampling point from the trunk. Their findings agree in general with earlier works reported by Beall (1934), Ovington (1954), and Geiger (1957). Such variations have been attributed to density of foliage immediately above the gage (Horton 1919). Most such conclusions, though logical, are not well supported, and, as pointed out by Helvey and Patric (1965a), do not adequately define relationships of an interlaced forest canopy, especially where there is more than one canopy level.

Stemflow is, as a rule, more variable than throughfall. Helvey and Patric (1965b) attribute this greater variability to the endless variety of branch arrangements and bark roughness between trees. In some studies there have been no strong correlations of several tree dimensions with stemflow (Black 1957). In a number of other studies summarized by Helvey and Patric (1965a), stemflow has been definitely associated with such factors as bark roughness, trunk diameter, and height of crown above the general canopy level. Lawson (1967) concluded that addition of a tree size variable greatly improved stemflow predictions for both pines and hardwoods.

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Opportunity for further analysis of the influence of canopy and tree variables on throughfall and stemflow was provided by measurements taken in connection with a study of soil moisture trends after clearcutting and thinning in a second-growth ponderosa pine stand in the Black Hills (Orr 1968). The accumulating evidence that interception reduces transpiration to some degree (Rutter 1968) makes it even more important that the throughfall and stemflow processes be understood and accounted for in hydrologic analyses.

Study Area

Throughfall was measured on three 30- by 30-foot subplots each in a 120- by 150-foot thinned plot and in an adjacent unthinned plot in second-growth ponderosa pine about 70 years old. The thinned stand had 435 trees per acre averaging 36 feet tall and 5.8 inches diameter, breast high (d.b.h.). The adjacent unthinned stand contained 2,885 trees per acre averaging 29 feet tall and 3.5 inches d.b.h.

Stemflow was measured on all 10 trees o one 30- by 30-foot thinned subplot, and on random sample of 10 out of 54 trees on on 30- by 30-foot unthinned subplot.

The plots were on the lower and mor gently sloping (9 percent) portion of a stee north- to northeast-facing slope. Soils appeare to have developed in place from limeston parent material. Site index is between 70 an 75, near maximum for ponderosa pine in th Black Hills. Precipitation averaged 21.3 inche per year over a 5-year period. Precipitatio usually is minimum during the winter, build to a maximum in June, and declines graduall through the summer and fall.

Methods

Throughfall was measured with two standar 8-inch cans rotated about a system of 10 random points on each of the three subplots i each of the two treatments. Hence, 30 point were sampled in each treatment. Measurements were taken yearlong at minimum 1-weel

Two standard 8-inch cans were rotatec about a system of 10 random points or each of three subplots in each of twc treatments to measure throughfall.

ntervals for 3 years. Occasional in-between measurements were taken in case of large storms. Gages were weighed and contents converted to inches depth. The two gages on each subplot were moved to another pair of points after any measurement period in which gross precipitation equaled or exceeded 0.05 inch. Because gages were located at only two of 10 sampling points per subplot at any given time, there are five different sets of precipitation data, each representing a different set of six gage points.

Stemflow was collected in copper collars attached to the trees and sealed with plastic cement. Collar openings were about one-half nch. The water was piped to 6-gallon containers and weighed for each tree. Stemflow was measured for 2 years.

Gross precipitation was measured with both a recording and standard gage in a nearby forest opening with minimum 45° clearance, and in one standard gage near the center of a 120- by 150-foot clearcut plot adjacent to the thinned and unthinned plots. Oil was used in all gages to minimize evaporation.

Canopy was photographed from ground level at each of the 30 throughfall gage points in each of the two treatments, with the hemispherical camera described by Brown (1962). Percentage canopy was estimated in each of 30 equal hemisphere segments from zenith to 90°. Values were averaged for an assortment of zenith and azimuth segments. Estimates were made by two different individuals and repeated by one individual after several months had elapsed. There was practically no difference n estimates between individuals or between repeat estimates by the same individual.

Tree measurements, including d.b.h., height to live crown, total height, and crown diameter were made by standard mensurational techniques.

Only the summer rainfall data (May-September, 1958-60 inclusive) were analyzed in detail. Winter and spring data were complicated by occasional mixed rain and snow, and by recording difficulties.

The principal throughfall analyses involved stepwise regression of throughfall on rainfall variables for each gage point, followed by regression of mean throughfall at individual points on canopy density. The precipitation variables tested in the initial analyses were gross rainfall, number of storms per observation nterval, and an expression of rainfall intensity. In the final analysis, all 30 sampling points n each treatment and the two treatments were combined.

Stemflow analyses involved regression of stemflow on rainfall variables for individual sample trees, introduction of tree variables, and final combination of all sample trees in the two treatments.

Assumptions of linearity were checked. Results did not justify an attempt to fit curves in either the throughfall or stemflow analyses.

Results

Throughfall

Rain throughfall was more variable in the unthinned than in the thinned stand. Mean canopy density in full azimuth, 52° zenith projection, ranged from 28 to 48 percent and averaged 42 percent in the thinned stand, and ranged from 52 to 75 percent and averaged 66 percent in the unthinned. Part of the greater throughfall variability in the unthinned stand was obviously due to greater magnitude of sampled drip concentration there. At one point, for example, where measured canopy density was 70 percent, the recorded throughfall was two to three times greater than gross rainfall, but only for gross rainfall amounts exceeding about 2 inches. Similar results have been reported by other investigators (Ovington 1954, Wicht 1941).

In all of the 30 individual sampling-point regressions in each of the two treatments, gross rainfall alone accounted for 92.9 to 99.7 percent of throughfall variation in the thinned stand and from 85.5 to 99.7 percent in the unthinned. Number of observations per gage point ranged from 8 to 12. The rainfall intensity variable was also highly correlated with throughfall at 24 to 30 points in both the thinned and unthinned stands, and the number of storms per observation interval (3-hour separation) was significantly correlated with throughfall at more than half the sampling points in both treatments. However, neither of these variables accounted for significant throughfall variation after gross rainfall in either treatment. Canopy density did not account for a consistently significant proportion of throughfall variation for different storm observation groups in the separate treatments. The range of canopy density was apparently too narrow. When the two treatments were combined, however, the range was broadened sufficiently for valid expression of the effect of canopy on throughfall.

The final regressions of throughfall (Y_1) on gross rainfall (X_1) alone were:

Thinned

$$Y_1 = -0.004 + 0.888X_1 \qquad (R^2 = 0.96)\ [1]$$

Unthinned

$$Y_1 = -0.054 + 0.813X_1 \qquad (R^2 = 0.82)\ [2]$$

Combined regression for thinned and unthinned, incorporating the 52° zenith projection full azimuth canopy density variable [X_2] expressed in percent yielded the following equation:

$$Y_2 = 0.167 + 0.851X_1 - 0.0037X_2 \quad (R^2 = 0.89)\ [3]$$

Throughfall estimates from separate equation [1] and [2] are compared with estimates for both treatments obtained with equation [3] (table 1). Equation [3] estimates mean throughfall from the mean of gross rainfall with adjustment for canopy density.

Mean canopy densities for other zenith projections and in the azimuth range of prevailing winds were computed, but those tested were interrelated to so high a degree that no single one was significantly better than another. This does not mean that closer relationships or better expressions of canopy density do not exist. A more efficient sampling scheme specifically designed for the purpose will be necessary to establish such relationships. Nevertheless, the present study clearly demonstrates use of canopy density parameters to quantitatively account for a portion of throughfall variation.

Stemflow

All completely recorded amounts of gross rainfall larger than 0.2 inch yielded measurable stemflow from at least one gaged tree in one or the other of the two treatments. The final analysis involved 21 summer rainfall events larger than 0.2 inch in both of the treatments over the 2 years of measurement.

Table 1.--Regression estimates of mean throughfall using equations 1, 2, and 3

Item	Observation group[1]				
	1	2	3	4	5
$\overline{X}_1$ Mean observed gross rainfall (inches)	0.680	0.430	0.751	0.866	0.743
$\overline{X}_2$ Observed mean canopy density (percent) 52° zenith projection, full azimuth					
Thinned stand	41.8	41.8	41.0	40.3	43.3
Unthinned stand	67.3	64.2	66.3	69.0	61.8
$\overline{Y}$ Mean observed throughfall (inches)					
Thinned stand	.59	.41	.66	.77	.63
Unthinned stand	.47	.31	.54	.58	.64
Y_1 Estimated mean throughfall (inches)					
Thinned stand (Eq. 1)	.60	.38	.66	.77	.66
Unthinned stand (Eq. 2)	.50	.30	.56	.65	.55
Y_2 Estimated mean throughfall (inches) from mean gross rainfall with adjustment for canopy density (Eq. 3)					
Thinned stand	.59	.38	.65	.75	.64
Unthinned stand	.50	.30	.56	.65	.57

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[1] Each group represents a set of six gages, each set having a different group of rainfall event due to gage rotation.

Here, as in the case of throughfall, gross rainfall was the only significant precipitation variable in combined regressions. The combination equations for regression of pounds of stemflow (Y) on gross rainfall (X_1) for all 10 trees in each of the two treatments are:

Thinned

$$Y = -1.94 + 13.21X_1 \qquad (R^2 = 0.57) \qquad [4]$$

Unthinned

$$Y = -2.43 + 13.09X_1 \qquad (R^2 = 0.31) \qquad [5]$$

$$X_1 \geq 0.2 \text{ inch}$$

The addition of tree variables greatly improved on these regressions. All three variables tested—d.b.h., tree height, and crown volume (taken as volume of cylinder whose diameter = mean crown diameter)—were significantly correlated with stemflow, but height and crown volume were not significant after d.b.h. because of high intercorrelation. R^2 values increased to 0.66 and 0.50 for thinned and unthinned stands, respectively, after including d.b.h. D.b.h. appears to be more important in the unthinned stand, considering the greater increase in R^2.

The regression equation after combining the two treatments and incorporating d.b.h. (X_2) is:

$$Y = -21.18 + 13.10X_1 + 4.49X_2 \quad (R^2 = 0.55) \qquad [6]$$

$$X_1 \geq 0.2 \text{ inch}$$

Estimated equivalent areal depth would be equal to estimated pounds for the average size tree on a given sample area, times the number of trees, converted to volume and divided by land area. Size of trees involved in this study ranged from 2.9 to 6.6 inches d.b.h.

Throughfall and Stemflow Combined (Net Rainfall)

Addition of throughfall and stemflow yields net rainfall, here defined as depth of rainfall reaching the surface of the forest floor. In the study area there was virtually no understory vegetation—just a bare mat of pine needles at the forest floor surface. Combination of equations [3] and [6] yielded the following equation for net rainfall:

$$\begin{aligned} Y = {} & n_1 (0.167 + 0.851\overline{X}_1 - 0.0037\overline{X}_2) \qquad [7] \\ & + n_2 N(-0.0000936 + 0.00005783\overline{X}_3 \\ & + 0.00001986\overline{X}_4) \end{aligned}$$

where

Y = Net rainfall (inches)
n_1 = Number of recorded precipitation events $\geq$ 0.05 inch
$\overline{X}_1$ = Average depth (inches) of all precipitation events $\geq$ 0.05 inch
$\overline{X}_2$ = Average canopy density (percent)
n_2 = Number of recorded precipitation events $\geq$ 0.20 inch
$\overline{X}_3$ = Average depth (inches) of rainfall events $\geq$ 0.20 inch
$\overline{X}_4$ = Average d.b.h. (inches) of all trees on sampled area
N = Number of trees per acre

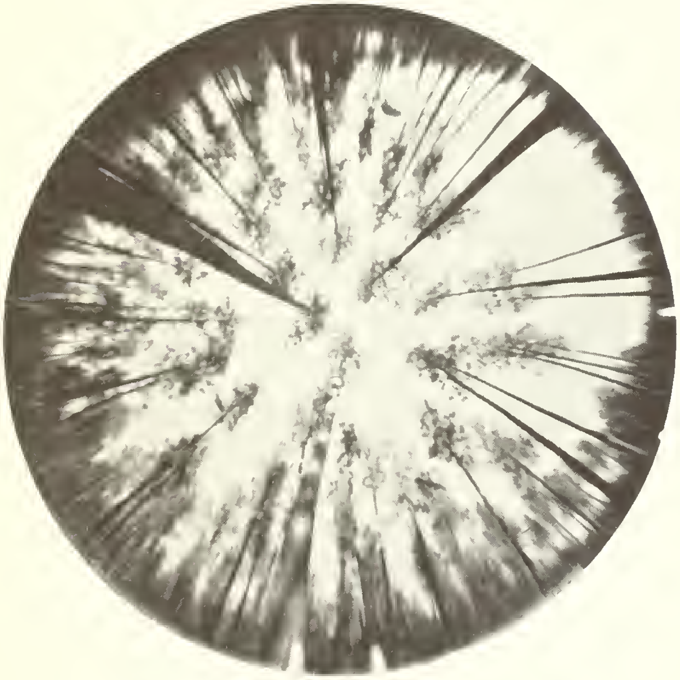
The first part of the equation provides an estimate of throughfall adjusted for canopy density, and the second part an estimate of pounds of stemflow converted to inches depth according to tree d.b.h. and number of trees per acre. This relationship is based on and hence is strictly applicable to a rather narrow situation—one forest type, one age class, and one climatic regime—in which only precipitation amounts equal to or larger than 0.05 inch were considered.

However, considering the surprising similarity of results from studies of different species at widely separated locations, it seems likely that the equation may yield realistic estimates of the relative magnitude of net rainfall (or interception loss) over a much larger area. For such use the exact method of determining canopy density probably is not critical so long as it is consistent.

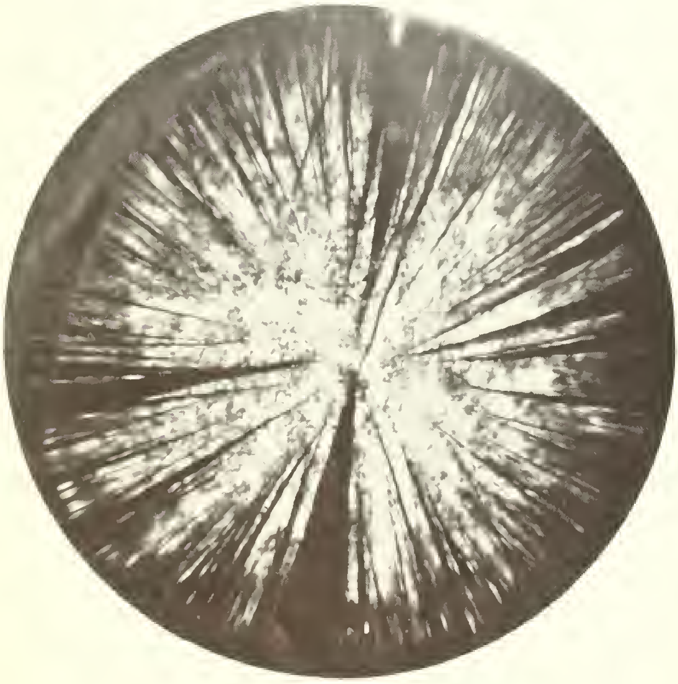
Summary and Discussion

This study demonstrates a possible method of estimating net rainfall in relation to stand density of second-growth ponderosa pine in the Black Hills. As in virtually all reported studies in both conifer and deciduous forest types, gross precipitation depth is the primary

Canopy was photographed from ground level at each of 30 throughfall gage points in each of two treatments, with a hemispherical camera (Brown 1962):



This thinned stand has 435 trees per acre (N), averaging 5.8 inches d.b.h. ($\overline{X}_4$). Canopy density ($\overline{X}_2$) is about 41 percent (in 52° zenith projection). Consider a single storm of 0.75 inch ($n_1 = 1$, $n_2 = 1$, $\overline{X}_1 = 0.75$, $\overline{X}_3 = 0.75$). Applying equation [7], throughfall is calculated as 0.65 inch and stemflow 0.03 inch, for a total net rainfall of 0.68 inch, or 91 percent of the amount of rainfall reaching the ground in the open.



This unthinned stand has 2,885 trees per acre (N), averaging 3.5 inches d.b.h. ($\overline{X}_4$) Canopy density ($\overline{X}_2$) is about 66 percent (in 52° zenith projection). Consider a single storm of 0.75 inch ($n_1 = 1$, $n_2 = 1$, $\overline{X}_1 = 0.75$, $\overline{X}_3 = 0.75$). Applying equation [7], throughfall is calculated as 0.56 inch and stemflow 0.06 inch, for a total net rainfall of 0.62 inch, or 83 percent of rainfall reaching the ground in the open.

controlling variable in both throughfall and stemflow. This primary control is clearly obvious in studies that have involved regression analyses. However, a combination of results from adjacent thinned and unthinned plots accounted for an additional small but nevertheless significant proportion of both throughfall and stemflow variances. This provided the basis for adjusting throughfall for percent canopy density and adjusting stemflow for tree d.b.h. The combination of these two relationships yields an equation for net rainfall.

Canopy density is the most obvious factor that it would be expected might influence throughfall. However, other researchers, as pointed out earlier, have concluded that there is no consistent evidence that interception losses are greatly affected by a variety of canopy densities. The overpowering influence of gross precipitation in the ordinary regression approach is very likely one of the main reasons for this lack of consistency. In the present study, using stepwise regression, canopy density also was not significant until results from adjacent thinned and unthinned plots were combined. The combination resulted in a broad enough range of canopy density to define a significant relationship.

A variety of canopy measurements involving average percent density in different zenith projections and/or azimuth segments were tested. Densities were estimated from vertical photos taken from the ground upward at each of the throughfall points, 60 in all. Because of intercorrelation and small residual variance after gross rainfall, no one canopy variable tested significantly better than another. On a rational basis the average density in 52° zenith projection, full azimuth, was used in final analysis.

Similar tendencies were evident in stemflow regression analyses. A variety of tree size variables were tested, including d.b.h., total height, and crown volume. Each correlated with stemflow independently, but in stepwise regression neither height nor crown volume were significant after d.b.h. because of intercorrelation.

The foregoing indicates statistically definable relationships of canopy density with throughfall and tree size with stemflow. Where or when more detailed information is needed for solution of specific hydrologic problems, other sampling design and analysis techniques may yield better defined relationships. In the meantime, entry of appropriate stand measurements in the combined equation [7] will yield a realistic idea of the magnitude of net rainfall (or interception) in relation to stand density of second-growth ponderosa pine.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-211

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Emergence, Attack Densities, and Seasonal Trends of Mountain Pine Beetle *(Dendroctonus ponderosae)* in the Black Hills

J. M. Schmid[1]

Beetles began emerging around July 1 and emerged in peak numbers on August 15, 1966 and 1967. Adults emerged almost simultaneously from the north and south sides of trees. More beetles emerged from the south side at 1.5 feet aboveground than from the north side at the same height, but this relationship was reversed at heights of 5 feet and 10 feet. Densities of beetle attacks varied significantly with height and aspect. Brood densities declined drastically between the time of attack and the following May. Relationships between beetle emergence, evaluation techniques, and control operations are discussed.

Keywords: Dendroctonus ponderosae, Pinus ponderosa, insect habits.

The success of efforts to evaluate or control populations of mountain pine beetle, Dendroctonus ponderosae Hopkins (Coleoptera: Scolytidae), depends partially on coordinating the effort with a particular event in the beetle's life cycle. If chemicals are applied after beetles begin emerging, the efficiency of the control effort decreases each day thereafter. If bark samples are taken after emerging has begun, incorrect estimates of beetle trends may result. Thus, we need to know accurately the timing of events in the life cycle.

Unfortunately, there are no uniform dates for these events for the Rocky Mountain region because they vary with geographical location and fluctuations in climate and weather. Each specific area may have its own average dates for such events and even they may vary with weather conditions in a particular year. Since the habits and life cycle of the beetle vary, it is important that biological data from a given area be made known so evaluation and control procedures can be adjusted accordingly.

This Note is based on data gathered during a study of the predators of D. ponderosae in the Black Hills (Schmid 1968). It discusses the distribution of emerging beetles with respect to time, aspect, and height on the tree bole, density of attacks, and seasonal trends of brood density within the lower 15 feet of infested trees.

Study Area

The study area was located in the northern Black Hills of South Dakota, 2 miles southwest of Lead, in a 60- to 80-year-old second-growth stand of ponderosa pine (Pinus ponderosa Lawson). Dominant trees ranged from 10 to 20 inches diameter at breast height (d.b.h.), with the majority of the trees between 11 and 14 inches. Elevation of the area was between 5,700 and 5,800 feet.

Methods

Screen cages were used to record the field emergence of D. ponderosae adults. Well before the 1966 beetle emergence, 21 cages (McCambridge 1964) were attached to 10 trees attacked in August 1965. Twelve were attached with the midpoints 4 feet aboveground; nine with the midpoints 10 feet or more aboveground. Each cage covered 5 to 6 square feet of bark.

Similarly, 78 cages were attached to trees attacked in August 1966. Six of these cages covered 5 to 6 square feet of bark each, and

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were attached to three trees in October 1966. Midpoints of the cages were 4 feet aboveground. The other 72 cages covered 2 square feet each, and were attached to 12 trees during May and June 1967. Six cages were attached to each tree, three on the north and three on the south side at heights of 1.5, 5, and 10 feet aboveground. The cages were checked at 2- to 3-day intervals until *D. ponderosae* adults began emerging, and usually daily thereafter in both years.

Bark samples, 6 by 12 inches, were removed at 1.5, 5, 10, and 15 feet aboveground from 20 infested trees in both 1966 and 1967. The 20 trees were separated into two equal groups. Each group was sampled once during the August-October period following the attack of *D. ponderosae*, and then alternately on a weekly basis from May through August of the following year.

Number of attacks, inches of gallery, and live beetles were counted in each bark sample. The data from each group were combined for each year and then a square root transformation $\sqrt{x + 3/8}$, was applied to the data before analysis of variance with respect to trees, height, time, and the interactions of height and time. A significance level of 0.05 was used for the analyses.

Results and Discussion

Emergence

Adults first emerged on June 29, 1966 and June 30, 1967. A few beetles emerged earlier, but this premature emergence probably was stimulated by cage attachment. The number of emerging beetles gradually increased during July and early August in both years, so that by August 5 approximately 10 percent of the beetles had emerged (figs. 1, 2). The mass emergence period began around August 10 in both years and continued until August 26 in 1966 and August 23 in 1967. The number of emerging beetles peaked on August 15 in both years, and fluctuated sharply from day to day. A few beetles (less than 0.2 percent of the total) emerged in September.

Daily emergence was affected by temperature, especially during the mass emergence period (figs. 1, 2). When maximum temperatures were 55° F. or lower, practically no beetles emerged; when maximum daily temperatures were above 55° F., the influence of temperature was less pronounced. Beetles emerging in a temperature range of 60° to 80° F. appear to be influenced more by factors such as the amount of cloud cover, relative humidity, and so forth, than by minor changes in maximum daily temperatures within this range.

Adults at the 5- and 10-foot heights emerged almost simultaneously from the north and south sides of infested trees in 1967; beetles at the 1.5-foot height usually emerged slightly earlier from the south sides.

The mean number (95 percent confidence interval) of *D. ponderosae* adults emerging per square foot of bark from the north and south sides of trees in 1967 was:

Height (feet)	North	South
1.5	16.5 ± 11.4	25.5 ± 10.6
5	30.8 ± 13.9	25.8 ± 15.0
10	30.9 ± 15.2	23.3 ± 8.6

The number emerging from the south side at 1.5 feet was significantly greater than the number emerging from the north side at that height. Differences between the north and south sides at the 5- and 10-foot heights were not significant although, on the average, more beetles emerged from the north sides.

The emergence information suggests several guidelines for the present methods of evaluating and controlling beetle infestations in the Black Hills. Since beetles may emerge in late June control projects should end by July 20. Treatment of infested trees after July 20 becomes progressively less effective each day. Biological evaluations based on Knight's sequentia sampling plan (Knight 1960) should also be completed by July 20. Samples taken after August 5 may give beetle estimates at least 10 percent low; this could result in an infestation being classified in a less important category. Since future research may also depend on accurately determining the time of emergence, the screen emergence cages should be in place by July 20.

Crews may continue their control or evaluation operations beyond July 20 if they know the beetles have not begun to emerge. However, these operations become progressively inefficient after July 20 and could lead to wrong conclusions about the status of the future infestation. It should also be stressed that the July 20 date is most applicable in the northern Black Hills, and should not be applied elsewhere without verification.

The placement of emergence cages on a specific side of a tree does not appear critica as long as the cages are placed around 5 feet aboveground, since the north and south sides

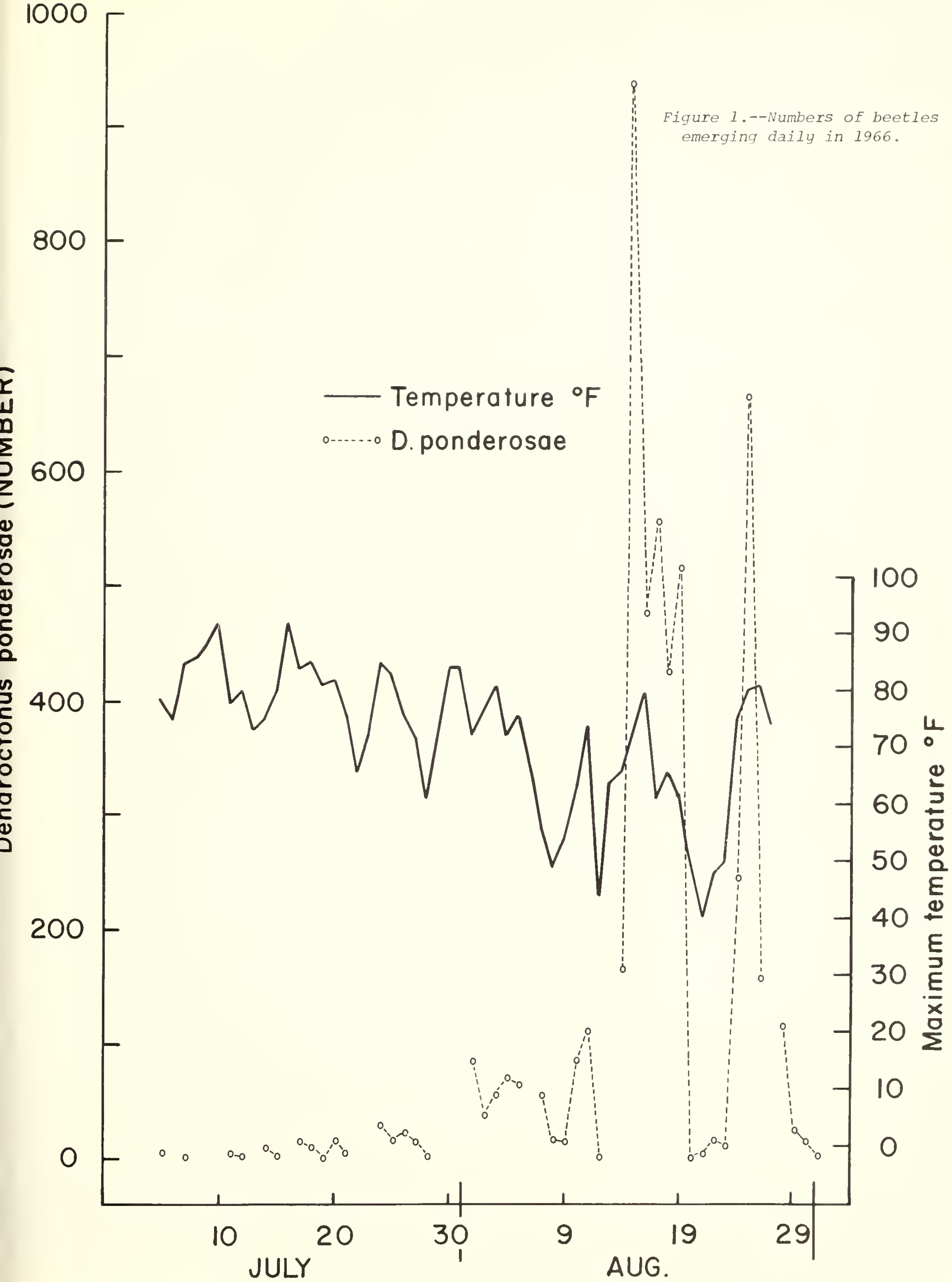

Figure 1.--Numbers of beetles emerging daily in 1966.

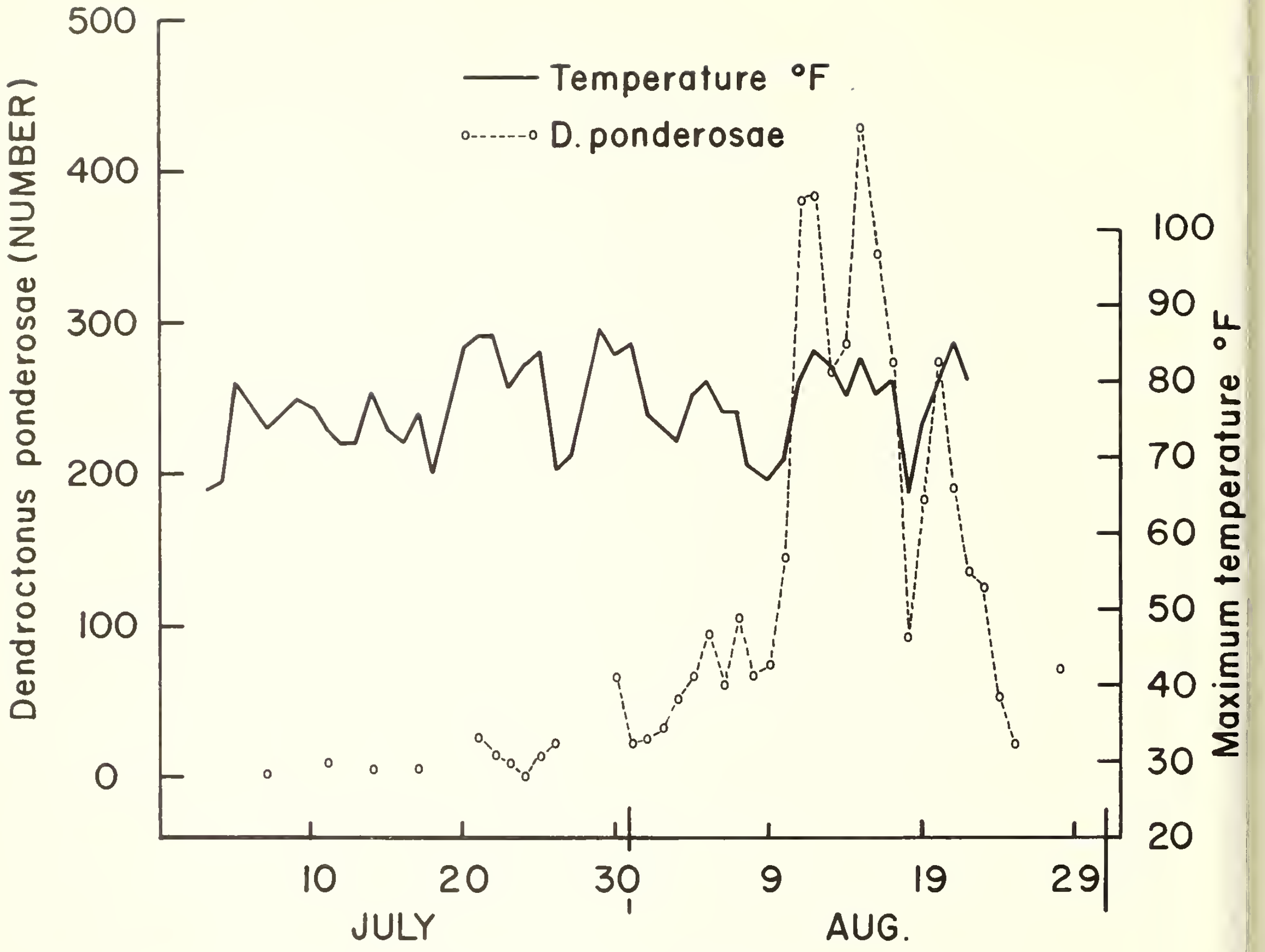

Figure 2.--Numbers of beetles emerging daily in 1967.

are not significantly different in either time or emergence or number of beetles. It may be preferable to place the cages on the north side because they produce a slightly greater number of beetles. This agrees with the observations of McCambridge (1964) on D. ponderosae in Colorado.

Density of Attacks

The density of attacks was significantly different between heights and aspects in both years. Interactions between the groups, heights, and aspects were not significant in either year.

The significant difference associated with height reflects the slight decrease in the mean density at the 15-foot level versus the mean densities at the other levels (table 1). Thi results because beetles generally did not attac when the bole diameter became less than inches. However, since the sample trees included a range of diameters 8 inches an greater at the 15-foot level, the rapid decreas in attacks is not immediately apparent.

The greater attack densities at the 5-foo level reflect characteristics of the flight behavior of the beetle. Beetles were observe flying into trees from 5 to 10 feet abovegroun during initial attack. Many bounced off th tree and fell to the ground or lower on th tree. Then they began climbing up the tre and started their attack. Attack densities a the base of the tree probably reflect this behavior, and also explain why densities ar nearly identical to those at the 5- and 10-foo levels.

Table 1.--Mean number of attacks per square foot by aspect and height for 1965 and 1966 (95 percent confidence interval)

Year	Height (feet)	Aspect				Mean
		North	East	South	West	
1965	1.5	6.6 ± 0.34	6.8 ± 0.42	6.8 ± 0.38	6.4 ± 0.40	6.5
	5.0	7.0 ± .44	7.2 ± .34	7.0 ± .30	5.8 ± .50	6.8
	10.0	6.4 ± .36	5.9 ± .46	6.2 ± .54	5.2 ± .42	5.9
	15.0	5.0 ± .38	5.2 ± .34	4.1 ± .40	4.2 ± .44	4.6
1966	1.5	11.2 ± .78	10.0 ± .58	12.1 ± .46	11.1 ± .64	11.1
	5.0	11.3 ± .66	10.9 ± .60	11.3 ± .54	12.2 ± .56	11.4
	10.0	12.5 ± .62	10.5 ± .52	10.4 ± .52	11.2 ± .66	11.2
	15.0	11.1 ± .66	9.3 ± .68	9.1 ± .56	9.5 ± .72	9.8

The differences in attacks associated with aspect are not readily explainable. The west aspect in 1965 and the east in 1966 had lower mean densities and thus influenced the statistical tests. Why they had lesser attack densities is unknown, but it may be related to high temperatures and light intensities (Shepherd 1965).

Although interactions did not show significance, it is interesting to note the relationship between density of attacks on the north and south sides at different heights (table 1) and the number of beetles produced at those heights for 1967. The mean density of attacks on the south side was greater at the 1.5-foot height, equal at the 5-foot height and considerably less at the 10-foot height than the mean density of attacks on the north side at corresponding heights (table 1). Numbers of emerging beetles followed the same pattern, except numbers were greater at the 5-foot height on the north side. This indicates that up to the attack densities reported here, numbers of emerging beetles increase with increases in attack densities. Apparently, attack densities did not reach a point where the effects of competition begin to cause a decrease in numbers.

Attack densities may not always indicate competition or population trend. As Cole (1962) points out, other factors affecting young larvae could reduce the brood arising from extremely dense attacks (18 per square foot) to the point where competition is not important. Obviously, the densities reported here are similar to the "normal" densities of 9 and 7 per square foot reported by Cole (1962) and McCambridge (1967), respectively. However, as Miller and Keen (1960) suggest, beetles distribute their attacks so that overcrowding does not occur in any particular bark area. Furthermore, although the number of attacks varies considerably, it always remains within certain limits. In this case, it is apparent that the number of attacks is fairly uniform within the tree but varies from year to year (table 1). This distribution pattern probably results from attack-inhibiting behavior such as stridulation and pheromone masking. Rudinsky (1968) suggests that such behavior by D. pseudotsugae Hopkins prevents overinvasion of the host and resultant starvation of the brood. D. ponderosae probably has a similar behavioral pattern, but I believe stridulation may be more important than Rudinsky indicates in determining the density of attacks. Males stridulating around the gallery entrance would not only warn males away, but could also keep other females from constructing their galleries too close to the initial gallery. Field observations also indicated that some beetles constructed considerable lengths of gallery without depositing many eggs when the number of galleries per sample became large. Bark samples with over 100 inches of gallery were not uncommon. These two behavior patterns thus prevented overcrowding and reduced the potential number of larvae before they began competing.

The number of attacks that will kill a tree will vary with tree diameter, attack density, and height of attack. Assuming that beetles attack rapidly and follow the patterns previously discussed, it is estimated that an 11-inch d.b.h. tree would be killed by 510 to 940 attacks. Similarly, 1,560 to 2,860 attacks would kill a 15-inch d.b.h. tree. Furthermore, assuming a 1:1 sex ratio, this means that each 11-inch d.b.h. tree would absorb about 1,000 to 1,900 beetles while each 15-inch d.b.h. tree would absorb approximately 3,100 to 5,700 beetles. Numbers of beetles absorbed by trees of other diameters can be estimated by multiplying the total bark surface subject to attack by the mean density of attacks in table 1.

No new attacks were found after the overwintering period although less than 0.1 percent of the parent adults were extending galleries.

Brood Densities

The density of beetles changed drastically during development of the brood (fig. 3). Densities were highly variable shortly after attack, and most declined by at least 50 percent between time of attack and the following May. These two factors indicate why predictive sampling plans are not effective during this period.

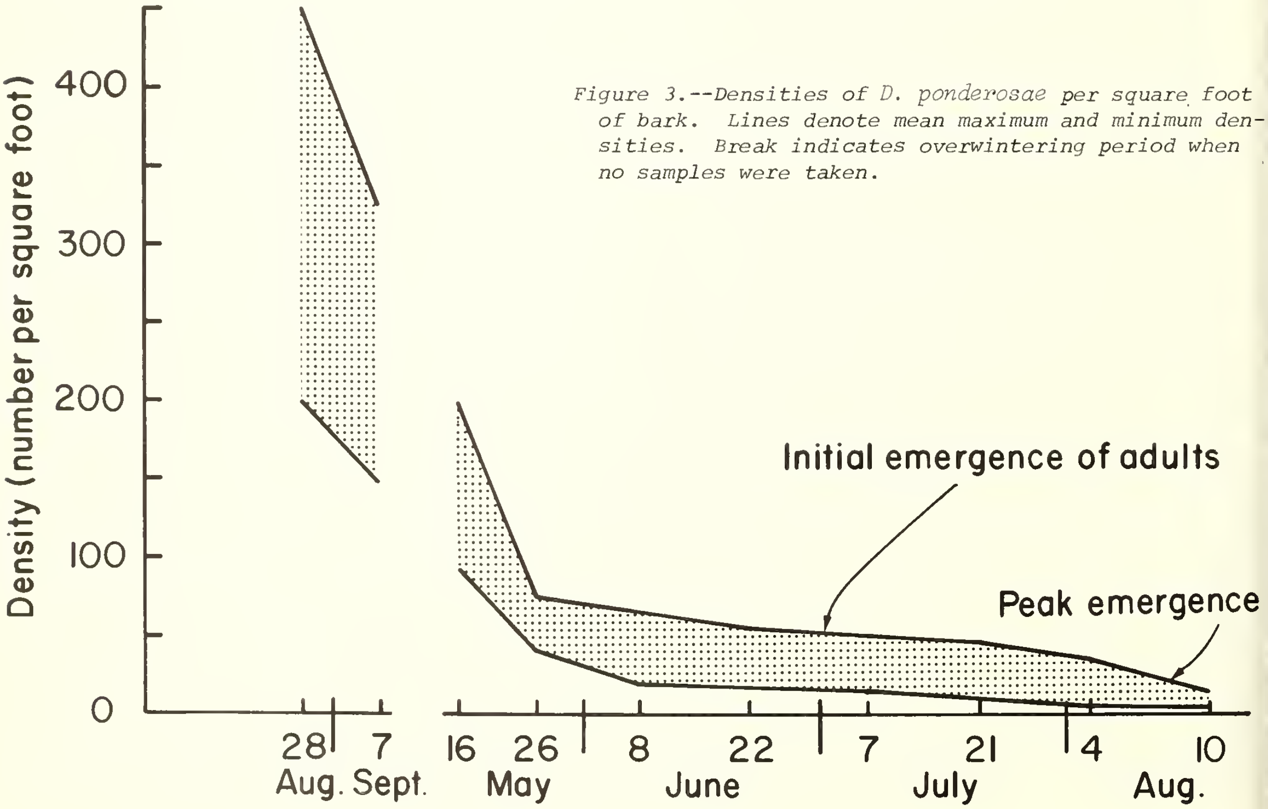

Figure 3.--Densities of D. ponderosae per square foot of bark. Lines denote mean maximum and minimum densities. Break indicates overwintering period when no samples were taken.

Densities gradually declined after the first of June. The difference between the maximum and minimum densities narrowed from June until beetles began emerging. Knight's sequential sampling plan (Knight 1960) is best applied during July when beetle densities are most similar and the least number have left the tree. The minor changes in brood densities after late May indicate that Knight's plan could be modified for control-no control decisions in late May.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-212

REST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Seasonal Variation in Wood Permeability and Stem Moisture Content of Three Rocky Mountain Softwoods

Donald C. Markstrom[1] and Robert A. Hann[2]

Time of year does not affect wood permeability but does affect water content of the trees, especially the sapwood. The water contents were highest during the winter.

Keywords: *Picea engelmannii, Pinus contorta, Pseudotsuga menziesii,* wood permeability, tree water content.

The Rocky Mountain region has a considerable potential for the production of poles from lodgepole pine (Pinus contorta), Engelmann spruce (Picea engelmannii), and Rocky Mountain Douglas-fir (Pseudotsuga menziesii). These species are not being used in proportion to their availability, however, because of (1) thin sapwood, (2) heartwood that is difficult to treat, or (3) incomplete preservative penetration of those with thicker sapwood.

This research was designed to gain information on the characteristics of these species that influence treatability. Specific factors studied were seasonal variations in longitudinal permeability and stem moisture content. Permeability directly influences flow of preservatives into wood, while high moisture content, especially in the sapwood, retards the entry of oil-borne preservatives. Any seasonal variation would therefore be of significance in the treating process.

Methods

Field Procedure

Ten trees of each species were sampled (table 1). The Douglas-fir were growing with ponderosa pine in a stand about 10 miles west of Fort Collins, Colorado. The lodgepole pine and Engelmann spruce were sampled at the Fraser Experimental Forest near Fraser, Colorado. The only criteria for selection were that the trees be of suitable size and shape for poles.

Five trees of each species were sampled during each of four physiological "seasons": (1) spring during the growing season, (2) summer, (3) fall after dormancy but before freezeup, and (4) winter during freezeup. Another five trees of each species were sampled monthly during the growing season. Sampling for stem moisture and permeability was extended into the second year to determine any annual change. Two increment cores of 0.5-inch diameter were extracted from equally spaced and randomly assigned positions around the stem at both the 3- and 5-foot levels above the ground. The cores were bored to a depth approaching the pith. One core from each level was cut into outer and inner sapwood and heartwood segments, and wrapped in heavy-

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[2] *Principal Wood Technologist, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.*

Stands where species were sampled:

Douglas-fir, west of Fort Collins.

Engelmann spruce, on Fraser Experimental Forest.

Table 1.--Growth characteristics of trees sampled

Species	Diameter at breast height		Age		Growth rings in center inch	
	Ave.	Range	Ave.	Range	Ave.	Range
	Inches		Years		Number	
Douglas-fir	10.77	9.3-12.2	75	64-108	32.4	26-38
Lodgepole pine	11.06	7.8-13.4	216	156-242	51.6	36-92
Engelmann spruce	12.41	9.7-16.2	139	100-187	25.3	14-38

Lodgepole pine, on Fraser Experimental Forest.

duty foil. Segments were weighed to the nearest 0.001 gram within 4 hours, ovendried at 103° C., and reweighed. Moisture contents were calculated on an ovendry basis. The other two cores were placed in glass vials filled with distilled water and immediately airmailed to the Forest Products Laboratory at Madison, Wisconsin, for permeability measurements.

Mechanical Preparation of Permeability Samples

The submerged cores were at 38° F., and green permeability measured within 1 to 2 weeks.

Four permeability test plugs—outer sapwood, inner sapwood, outer heartwood, and inner heartwood—each approximately 0.250 inch in diameter and 0.35 inch in the fiber direction, were cut from each core (fig. 1).

Distance from the cambium to the center of the sample plug was recorded, since it has been established that permeability decreases with increasing distance from the cambium (Comstock 1965). Liquid permeability was measured while each specimen was green; the specimen was then conditioned to approximately zero moisture content and the permeability to nitrogen gas was determined.

Permeability Measurement

The general equipment and procedures used to measure gas and liquid permeability have been previously described (Comstock 1965, 1967). A rubber stopper, drilled out in the center to hold the specimen, was placed in a chambe tapered at the sides to conform to the angula bevel of the stopper (fig. 2). A plunger designed to apply pressure was placed on to of the stopper. When the cap for the holde was tightened, the plunger was forced agains the rubber stopper. This in turn forced th stopper further down in the tapered chamber The compression of the stopper effectively seale the specimen so that flow was possible onl through the wood structure. Water permeability was determined over a 3-minute interval to insure that the apparatus was workin properly and that contamination of the permeating water was not a factor in the results

A tube of plexiglass providing a maximur hydrostatic head of approximately 80 centimeter of water was used to maintain flow throug sapwood permeability plugs. After the liqui passed through the test cell, the flow rate wa measured on a Brooks rotometer [3] to an accuracy of ± 1 percent.

The flow rate through heartwood was mor difficult to determine because heartwood ha relatively low permeability compared to sapwood Consequently, a graduated pipette was use in place of the rotometer. Pressure was applie to the water in the system with nitrogen regulated by a standard pressure regulator. Flov was established by recording the time of advance of liquid into the graduated pipette

After the liquid permeability was measured the specimens were dried and nitrogen ga

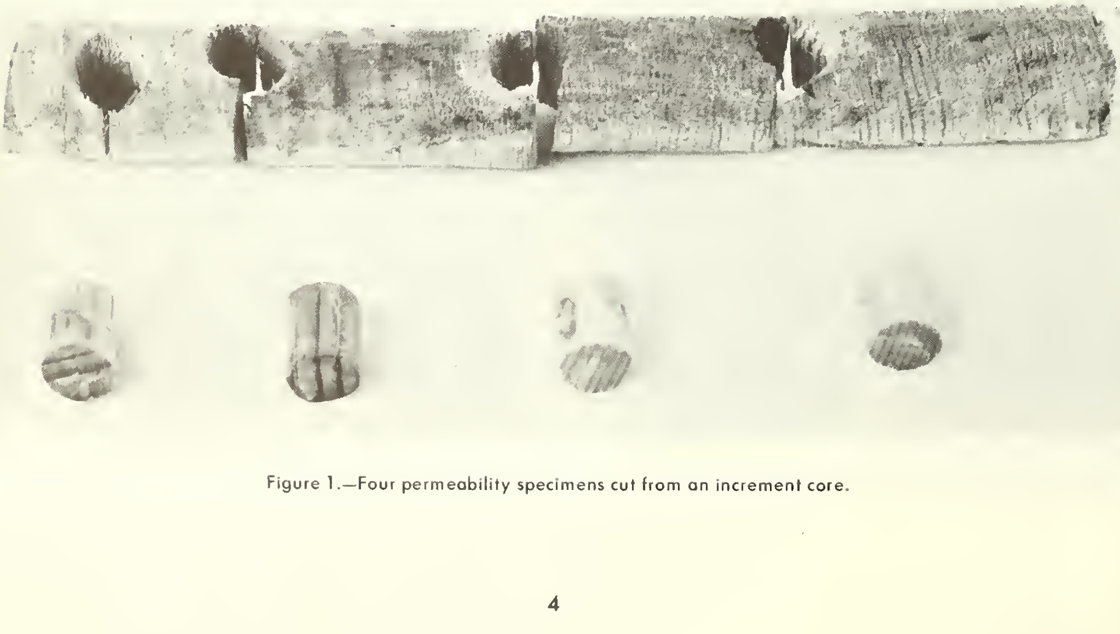

Figure 1.—Four permeability specimens cut from an increment core.

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[3] *Trade and company names are used for th benefit of the reader, and do not constitute endorsemen by the U. S. Department of Agriculture.*

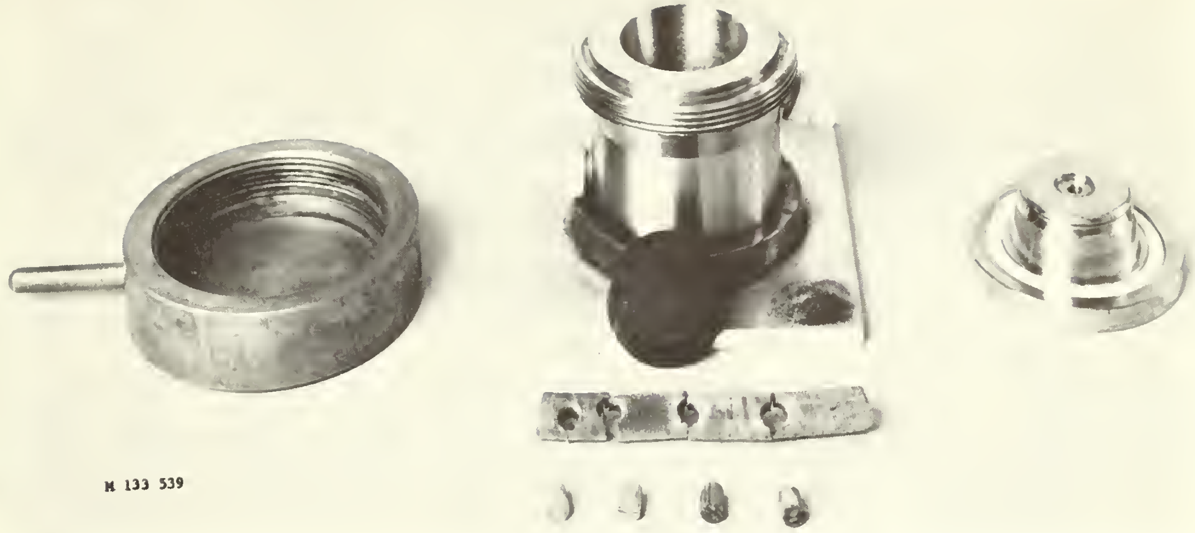

Figure 2.—The specimen is placed in the hole in the rubber stopper (center), the stopper is placed in the tapered housing (upper center), the plunger (right) is placed on top of the stopper, and finally, the cap (left) is tightened on the housing to force the plunger against the stopper, thus sealing the stopper tightly around the specimen.

permeability was measured. Details of the method are described by Comstock (1965). In general, the apparatus consisted of a nitrogen tank, a pressure measuring and regulating system, the specimen holder (fig. 2), and a series of rotometers. Gas permeability was measured at atmospheric pressure on the downstream side, while maintaining a pressure drop through the specimen of approximately 40 centimeters of mercury. The gas permeability values were not corrected for slip flow. Slip flow increases gas permeability slightly (Comstock 1967), but not enough to be of importance in this study.

Results

Permeability

Season did not have an apparent effect upon liquid or gas permeability. The data showed considerable variation among trees with a coefficient of variation of about 33 to 50 percent, but most of this must be attributed to factors other than season.

The liquid and gas permeabilities of the sapwood for all species were greater than those for the heartwood (table 2). The liquid permeability of the outer sapwood for all species was greater than that for the inner sapwood, but the heartwood portions did not differ appreciably. Gas permeabilities of the outer and inner portions of neither sapwood nor heartwood differed appreciably.

Stem Moisture

The moisture content of the outer and inner sapwood for the three species varied significantly with the "seasons." The sapwood moisture contents were the highest during the winter freezeup (table 3). Moisture contents of the trees during August 1968 were not significantly different from those of August 1967. Both the outer and inner heartwood of Douglas-fir showed no real change in moisture content throughout the year. These results agree with those reported for Engelmann spruce and lodgepole pine sapwood during the winter and fall (Swanson 1967), for Douglas-fir sapwood and heartwood (Parker 1954), and for ponderosa pine sapwood (Yerkes 1967).

Differences in moisture content between the two spring growing seasons and between months during the growing season are probably affected by current weather and moisture regimes (table 3).

Regression analyses showed no significant relationship between permeability and water content, either within sampling periods or over the duration of the study.

Table 2.--Permeability of outer and inner sapwood and heartwood of Douglas-fir, lodgepole pine, and Engelmann spruce

Permeability by species	Outer sapwood		Inner sapwood		Outer heartwood		Inner heartwood	
	Mean	Standard error	Mean	Standard error	Mean	Standard error	Mean	Standard error
	- - - - - - - - - - - Darcys[1] - - - - - - - - - - -							
Liquid permeability:[1]								
Douglas-fir	2.796	0.195	2.031	0.182	0.006	0.001	0.004	0.001
Lodgepole pine	3.029	.148	2.287	.129	.001	.0007	.001	.0004
Engelmann spruce	3.570	.287	2.042	.246	.007	.006	.010	.005
Gas permeability:[1]								
Douglas-fir	.035	.004	.032	.003	.023	.003	.020	.003
Lodgepole pine	.077	.006	.076	.005	.037	.002	.038	.003
Engelmann spruce	.079	.007	.069	.006	.032	.004	.034	.006

[1] Liquid permeability:

$$Darcys = K = \frac{QLn}{A\Delta P}$$

Gas permeability:

$$Darcys = K = \frac{QLn}{A\Delta P}\frac{p}{p'}$$

where

K = permeability (darcys)
Q = flow rate (cubic centimeters per second)
A = flow area (square centimeters)
L = flow length (centimeters)
ΔP = pressure drop (atmospheres)
n = viscosity (centipoise)
p' = mean absolute pressure within the specimen (atmospheres)
p = pressure at which the flow, Q, is measured (atmospheres)

Conclusions

Permeability of sapwood of the three species is greater than that of the heartwood; therefore sapwood-heartwood proportions would be expected to affect treatability.

Although time of year does not affect permeability, it does affect water content of the trees, especially of the sapwood. Since moisture content of the wood for most treating methods should be near or below the fiber saturation point (Hunt and Garratt 1953), trees harvested in winter would have to lose proportionately more water to be as treatable as trees harvested during the growing season.

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Table 3.--Seasonal variation in moisture content of outer and inner sapwood and heartwood of Douglas-fir, lodgepole pine, and Engelmann spruce

Species, by period of measurement	Outer sapwood		Inner sapwood		Outer heartwood		Inner heartwood	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	- - - - - - - - - -	- - - - - - - - - -	Percent of ovendry weight	- - - - - - - - - -	- - - - - - - - - -			
DOUGLAS-FIR:								
Spring growing (1967)	148	24	141	27	28	1	29	1
Summer	126	18	120	25	27	2	28	2
Fall dormancy	129	20	118	20	29	1	30	1
Winter	155	10	150	16	31	1	32	1
Spring growing (1968)	133	19	122	17	30	2	31	2
Summer	130	19	115	36	28	1	31	1
Month of growing season--								
May (1967)	124	23	115	23	29	2	28	1
June	118	16	119	18	28	1	29	1
July	117	19	118	17	28	1	29	1
August	108	27	101	23	26	1	28	1
September	119	15	114	17	28	2	29	2
August (1968)	113	28	108	22	28	1	29	3
LODGEPOLE PINE:								
Spring growing (1967)	138	25	138	22	35	6	43	8
Summer	145	22	144	16	42	20	48	13
Fall dormancy	161	18	147	31	39	14	47	15
Winter	173	18	164	16	43	9	68	27
Spring growing (1968)	127	30	131	17	36	6	47	11
Summer	150	29	150	21	42	20	55	16
Month of growing season--								
May (1967)	129	22	135	15	38	14	46	15
June	139	20	136	20	33	4	46	18
July	136	17	139	22	47	20	62	31
August	122	14	128	17	36	5	49	16
September	134	25	126	27	39	12	50	20
August (1968)	125	20	137	18	35	3	46	9
ENGELMANN SPRUCE:								
Spring growing (1967)	174	12	169	25	39	10	46	17
Summer	167	9	158	17	42	15	39	9
Fall dormancy	173	19	152	32	43	6	43	10
Winter	191	21	168	43	48	15	43	8
Spring growing (1968)	155	12	134	30	39	12	37	10
Summer	159	31	148	29	40	6	39	10
Month of growing season--								
May (1967)	185	25	171	22	48	16	43	9
June	165	22	156	30	45	21	47	28
July	176	17	178	27	44	10	45	23
August	170	20	160	28	47	14	47	14
September	170	19	177	19	40	5	38	4
August (1968)	167	20	161	29	45	13	46	10

Agriculture—CSU, Ft. Collins

U S D A FOREST SERVICE
RESEARCH NOTE RM-213

OREST SERVICE
S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Specific Gravity Variation with Height in Black Hills Ponderosa Pine

Donald C. Markstrom and Vern P. Yerkes[1]

Average specific gravity decreased with increasing height up the merchantable stem. The mature trees with d.b.h. 11.0 inches or less had the highest specific gravity at all stem levels. The table presented provides a means of predicting specific gravity at different relative heights of the merchantable stem.

Keywords: Pinus ponderosa, tree specific gravity, tree merchantable height.

Specific gravity is related to many properties of wood, such as strength and pulp yields (Markwardt and Wilson 1935, U.S. Forest Products Laboratory 1953). This characteristic of wood has been widely accepted as one of the major criteria for estimating wood quality, and is reported in the literature for most tree species in the United States.

Specific gravity varies, however, both between and within trees of the same species. Average specific gravity for ponderosa pine (Pinus ponderosa) trees generally decreases with increasing height up the stem (Conway and Minor 1961, Cockrell 1943). The effect of height upon specific gravity is especially important when considering multiproduct uses of the total stem. Because the upper portions of the stem have lower average specific gravity, they will produce wood with lower strength and lower yields of pulp per cubic foot.

This report describes how specific gravity varies with height in the merchantable stem of Black Hills ponderosa pine.

Methods

Data were collected from 226 trees sampled in earlier studies throughout the Black Hills of South Dakota and Wyoming (Landt and Woodfin 1959, Yerkes 1966). The sample trees (table 1) were separated into three groups: (1) all trees with d.b.h. greater than 11.0 inches, (2) mature trees with d.b.h. 11.0 inches or less, and (3) immature trees with d.b.h. 11.0 inches or less. Landt's study (1959) showed that the specific gravity of mature trees 11.0 inches d.b.h. or less was significantly higher than that of immature trees in that size class.

Specific gravities of the saw-log trees were determined from 12 mm diameter increment cores from heartwood and sapwood at the stump and near saw-log bucking points. The trees were bucked to a nominal 8-inch top. Specific gravities of the trees 11.0 inches d.b.h. or less were determined from wedge-shaped pieces of combined heartwood and sapwood cut from 1-inch disks at 100-inch intervals from the stump to a nominal 4-inch top. Specific gravities for all trees were calculated on the basis of green volume and ovendry weight.

Specific gravity versus merchantable height was fitted with power curves because specific gravity decreased most rapidly near the base and least rapidly near the top. The calculated regression curves were asymtotic to the X axis.

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Table 1.--Growth characteristics of sample trees

	Height		Growth rate	Age	Heartwood volume
	Total	Merchantable			
	Feet		Rings/inch	Years	Percent
D.b.h. 11.0 inches or less:					
Mature					
Average	51.0	32.0	35.0	132.0	16.1
Maximum	73.0	49.0	58.0	227.0	88.4
Minimum	30.0	17.0	20.0	78.0	0.0
Immature					
Average	44.0	27.0	17.0	69.0	3.6
Maximum	67.0	49.0	26.0	90.0	33.4
Minimum	30.0	17.0	10.0	42.0	0.0
D.b.h. above 11.0 inches:					
Average	66.0	44.1	17.0	150.0	12.9
Maximum	85.0	69.1	32.0	236.0	49.2
Minimum	44.0	22.5	7.0	70.0	0.7

Preliminary analysis of the data indicated that it would be misleading to compare specific gravities at absolute heights between trees of differing merchantable heights. To overcome this problem, the heights of the sampling points were changed to a proportion of merchantable height, and the corresponding specific gravities to relative specific gravities. The relative specific gravities were calculated by dividing the specific gravity at each sampling point by the specific gravity at 1 foot for each tree. Relative specific gravities at various proportions of merchantable height were fitted for the three classes of trees (table 2). Calculated specific gravities at various proportions of merchantable height are shown in table 3.

Table 2.--Regression equations to estimate relative specific gravity from proportion of merchantable height

Tree and wood characteristics	Number of trees in sample	Regression equation	Standard error	Correlation coefficient
D.b.h. 11.0 inches or less:				
Mature	47	$y = 0.87\ x^{-0.038}$	0.0019	-0.58
Immature	104	$y = 0.90\ x^{-0.031}$	0.0013	-0.53
D.b.h. above 11.0 inches:				
Weighted heartwood-sapwood	75	$y = 0.87\ x^{-0.036}$	0.0020	-0.58
Sapwood only	75	$y = 0.88\ x^{-0.035}$	0.0019	-0.56
Heartwood only	75	$y = 0.91\ x^{-0.023}$	0.0040	-0.22

Table 3.--Specific gravity at different proportions of merchantable heights[1] for three classes of sample trees

Proportion of merchantable height[1]	D.b.h. 11.0 inches or less		D.b.h. above 11.0 inches		
	Mature	Immature	Weighted heartwood-sapwood	Sapwood only	Heartwood only
0.01	0.48	0.44	0.44	0.43	0.49
.05	.45	.42	.41	.40	.48
.10	.44	.41	.40	.39	.47
.15	.43	.41	.40	.39	.47
.20	.42	.40	.39	.38	.46
.25	.42	.40	.39	.38	.46
.30	.42	.40	.39	.38	.46
.35	.42	.39	.38	.38	.46
.40	.41	.39	.38	.38	.46
.50	.41	.39	.38	.37	.45
.60	.41	.39	.38	.37	.45
.70	.40	.39	.37	.37	.45
.80	.40	.38	.37	.37	.45
.90	.40	.38	.37	.36	.45
1.00	.40	.38	.37	.36	.45

[1] Calculated as follows: Average specific gravity at 1 foot times fitted relative specific gravity at particular proportion of merchantable height.

Results and Conclusions

The immature trees with d.b.h. 11.0 inches or less have the same or slightly greater specific gravity as all trees with d.b.h. above 11.0 inches at all percentages of merchantable height (table 3). It is felt that difference in measuring technique (wedges versus increment cores weighted by volume of sapwood and heartwood) may attribute to the differences in specific gravity of the two above classes of trees. The mature trees with d.b.h. 11.0 inches or less have a higher specific gravity than either the immature trees or all trees with d.b.h. above 11.0 inches. Although the specific gravity of the heartwood for the trees with d.b.h. above 11.0 inches is considerably higher than that for the sapwood, the weighted specific gravity is only slightly higher because of the small volume of heartwood. The presence of extractives would contribute to both higher and more variable specific gravity values found in the heartwood.

The correlation coefficients of the regression equations to estimate relative specific gravity from proportion of merchantable height indicated a better or nearly as good a fit in some cases as did curves relating specific gravity to either absolute or proportion of merchantable height. Thus, the specific gravity at any point along the merchantable stem of trees with different total heights can be determined from table 3.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-214

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Litter Production by Oak-Mountainmahogany Chaparral in Central Arizona[1]

Charles P. Pase[2]

Annual litter fall from shrub live oak was 192 g/m^2 crown area on southerly slopes, and 138 g on northerly slopes. For the chaparral community as a whole, southerly aspects produced 193 g/m^2 crown areas and northerly aspects, 215 g. Most litter fell during late spring and early summer, least in fall and early winter. Forest floor varied from 9.2 to 27.1 metric tons per ha. Maximum water retained against free drainage was 4.8 mm under shrub live oak and 5.1 mm under Pringle manzanita.

Keywords: Chaparral, litter, oak, mountainmahogany, biomass, forest floor, *Cercocarpus montanus*, *Quercus turbinella*.

Chaparral is the dominant vegetation on some 1.6 million ha (4 million acres) in Arizona. Litter production and accumulation under this evergreen shrub cover has important effects on soil protection and consumptive water use, because the communities exist on steep slopes with highly erodible soils.

Litter production and accumulation ("forest floor") was studied intensively by Kittredge (1955) in the chaparral of southern California. He found significant differences between chaparral subtypes, and between young and old stands, both in annual production and accumulation. Nineteen-year means of annual litter accumulation ranged from 1.51 to 3.19 metric tons per ha in Bell Canyon, and 4-year averages ranged from 0.52 to 4.96 metric tons per ha in Fern Canyon. Weight of forest floor, or total accumulated litter, was calculated to range between 8.4 and 111.9 metric tons per ha at equilibrium, the point where annual accumulation equals annual decomposition. Kittredge estimated that about 12 metric tons of forest floor per ha would provide adequate watershed protection against erosion.

Glendening and Pase (1964) measured forest floor of 46.2 metric tons per ha under a dense, mature stand of Pringle manzanita (Arcto-

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staphylos pringlei Parry) in central Arizona. Litter depth was 3.5 cm. Forest floor depth of 1.3 cm or greater adequately controlled erosion in a ponderosa pine (*Pinus ponderosa* Laws.) area in California (Rowe 1955).

Precipitation intercepted and retained by litter affects the soil moisture regime, especially when moisture is derived from small showers. Kittredge found moisture retention storage to vary from 12 percent under chamise and Eastwood manzanita to 187 percent under chaparral whitethorn. Under *Quercus dumosa* Nutt., a shrub closely related to shrub live oak (*Quercus turbinella* Greene), retention storage was 157 percent.

The purposes of this study were to determine (1) the annual litter fall under shrub live oak and under a mixed chaparral stand, and to relate this litter fall to aspect, shrub size, and season of year; (2) weight of the forest floor; and (3) litter moisture retention capacity.

Study Area and Methods

Study sites were located in the Sierra Ancha Experimental Forest about 55 km north of Globe, Arizona, and in the Mazatzal Mountains within the Tonto National Forest.

Northerly (fig. 1) and southerly (fig. 2) aspect collection sites on the Experimental Forest were located at 1,500 and 1,585 m elevation, respectively, about 1.5 km apart. Both sites on the Experimental Forest were on deeply weathered diabase parent material. Soils, tentatively classified as Jayaar sandy loam, were coarse and almost structureless, with high infiltration capacity. Regolith varied from 2 to 3 m deep.

Shrub live oak was dominant, with true mountainmahogany (*Cercocarpus montanus* Raf.), manzanita (*Arctostaphylos* spp.) and Wright silktassel (*Garrya wrightii* Torr.) as common associates. The stand had not burned over for at least the last 75 years, as determined by ring counts on occasional ponderosa pine trees in swales (Pase and Johnson 1968).

Annual rainfall at Headquarters Climatic Station, midway between the two sites, has averaged 630 mm since 1914. Approximately 30 percent of this falls during the summer growing season, June through September—an unusual situation for "Mediterranean" type vegetation. Two dry seasons usually occur—April-June, and September-October.

Nine mature shrub live oak plants at each site were caged with hardware cloth to trap all litter produced. A floor of screen wire was fitted beneath each plant. Litter was collected monthly, as far as possible, from July 1962

Figure 1.—Litter collection area on sc th facing chaparral slope near Si rc Ancha Headquarters.

2.—Pocket Creek drainage. Arrow points north-facing litter collection site.

through September 1965. When weather delayed collection, the litter was prorated to a monthly basis.

Before the cages were placed, four 929 cm^2 (1 ft^2) samples of forest floor were collected under each shrub live oak. The "L" layer consisting of fresh, intact litter and "F" layer consisting of partially decomposed litter were measured for depth, then collected and ovendried.

To sample litter fall from the shrub community in general, 33 litter baskets 929 cm^2 in area were placed under shrubs on each of the two aspects. These baskets were collected quarterly, and litter fall prorated to the following periods: spring, March 21 to June 20; summer, June 21 to September 20; fall, September 21 to December 20; and winter, December 21 to March 20. Litter baskets were collected for 3 years, beginning in the fall of 1962. Although baskets were placed on slopes, litter weights were adjusted to reflect horizontal areas.

One collection site for determining moisture-retention capacity under a dense Pringle manzanita stand was located in the Mazatzal Mountains. Elevation of this site was 1,740 m, on deeply weathered granitic parent material. Soil was of the Barkerville series, coarse with high infiltration capacity, but with some clay in the subsoil. Slopes were less than 50 percent on all sites.

For determination of moisture-retention capacity, 16 circular 12.7 cm diameter disturbed-litter samples were randomly selected from one shrub live oak and two Pringle manzanita communities. The "L" and "F" layers were collected together; rock fragments and soil aggregates were removed by hand. Water-holding capacity was determined as outlined by Kittredge (1955) and modified by Bernard (1963). Litter samples in metal cylinders with cheesecloth bottoms were soaked in water for 48 hours, then drained on damp sand for 48 hours. Cylinders were covered with plastic to reduce evaporation. The drained litter was weighed and ovendried at 102° C for 48 hours.

Relative leaf mass on northerly versus southerly aspects was determined by cutting 111 shrub live oak stems on the northerly aspects, 100 on southerly aspects, then stripping and ovendrying the leaves. Stem diameters were measured near ground level, above any swelling.

Crown cover of the chaparral stand was determined by nine 100-foot line intercept transects on each of the two aspects.

Results

Litter Production

Shrub live oak produced an annual litter mass of 137.5 g/m^2 of projected crown area on northerly slopes, and 192.1 g/m^2 on southerly slopes. Because the shrubs were selected for suitability for caging as well as comparable size and health, no statistical comparison is valid (Kemp 1965). On the basis of 42.8 percent shrub live oak cover on northerly slopes and 40.2 percent on southerly slopes, this represents 588 kg and 772 kg shrub live oak litter per ha, respectively.

Virtually 100 percent of the leaves on healthy shrub live oaks were replaced each year—few leaves remained on the shrubs from one growing season to the next. On southerly aspects most litter was shed in April and May, followed by an abrupt decline that reached its low point in January. Litter yield from north-slope shrub live oaks, however, was shed more uniformly from April through August, and reached a low point also in January (fig. 3). Leaves comprised by far the greatest percent of annual litter shed:

	Northerly slopes	Southerly slopes
	(Percent)	
Catkins	1.75	4.22
Leaves	91.74	87.75
Twigs and bark	3.24	5.16
Acorns	2.26	2.55
Acorn cups	1.01	.32

Volume index (crown area × height) was only a slightly better estimator of litter production than projected crown area (r = 0.965 vs r = 0.946), because the individual caged shrubs were relatively uniform in height. Annual litter fall increased approximately 0.1 kg for each cubic meter increase in shrub crown volume (fig. 4).

Shrub live oak leaf mass in this mature chaparral community was closely related to stem basal area (fig. 5). There was no significant difference between northerly and southerly slopes. Stems varied considerably in height, so incorporation of this parameter would likely have reduced the variance of the leaf mass-basal area regression.

Litter yield from the total chaparral community was significantly higher on north- than on south-facing aspects. Litter baskets placed within the crown canopy collected a 3-year average of 193 g/m^2 on southerly slopes—similar to the annual rate found under shrub live oak. When corrected for 18 percent bare ground, on which the annual litter accumulation was unknown but very low, litter fall amounted to 1,580 kg per ha. On northerly slopes, however, litter fall per square meter from the total stand was substantially higher than from shrub live oak alone. Litter basket collections showed a litter fall of 215 g/m^2 within the canopy. When corrected for 19 percent bare ground, this is equivalent to 1,740 kg per ha. Shrub live oak, with 52 percent of the shrub composition, produced only 34 percent of the total north-slope litter.

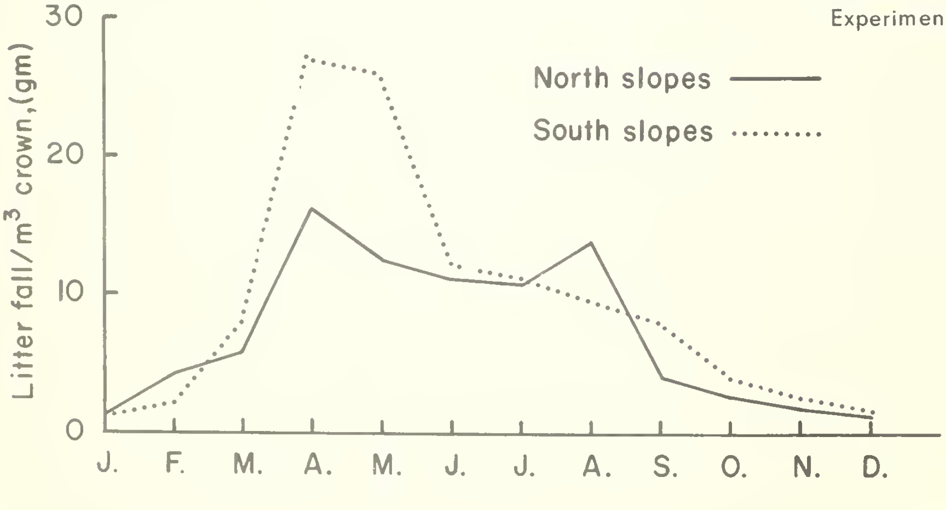

Figure 3.—Monthly litter fall from mature shrub live oaks on the Sierra Ancha Experimental Forest.

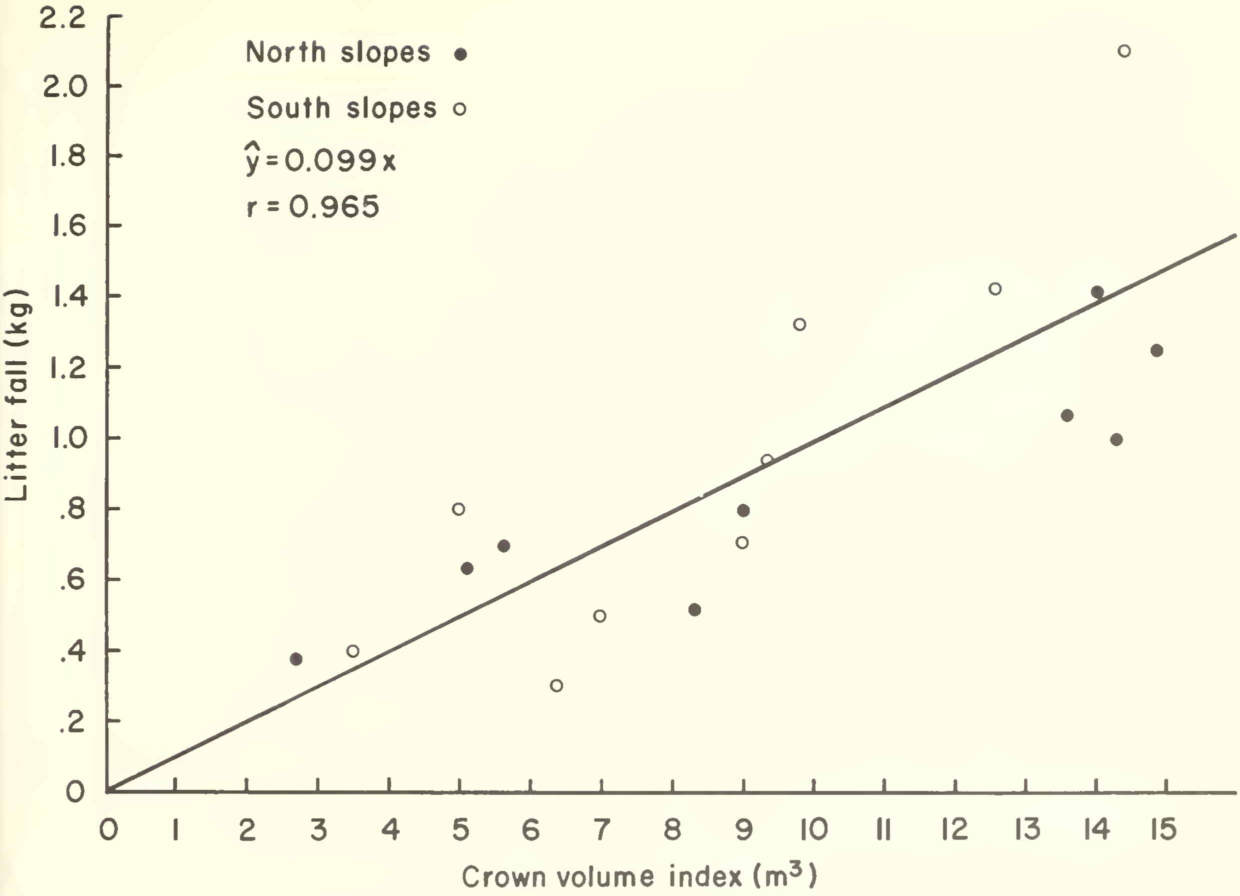

Figure 4.—Shrub live oak litter production as a function of crown volume index.

The peak of litter fall for the chaparral community as a whole was somewhat later than for shrub live oak alone. On both aspects, most litter fell during the summer, and least in the fall:

	North	South
	(g/m²)	
Spring	34.2	32.6
Summer	77.2	70.5
Fall	27.5	21.4
Winter	34.2	32.6
Total	215.3	193.2

Weight of Forest Floor

The lower shrub live oak litter production on north-facing slopes resulted in lower forest floor weights. On northerly slopes, total forest floor under the nine caged oaks averaged 9.2 metric tons per ha; on southerly slopes it averaged 16.4 metric tons per ha:

	Thickness (cm)	Ovendry weight (metric tons/ha)
North:		
L layer	0.25	0.8
F layer	2.44	8.4
South:		
L layer	0.25	1.8
F layer	2.31	14.6

Forest floor under three dense, mature, east-facing chaparral stands—one shrub live oak and two Pringle manzanita—was substantially heavier than under the individual caged shrub live oak plants. Litter mass in the combined "L" and "F" layers was 27.1 ± 1.2 metric tons per ha under predominantly shrub live oak, and 25.1 ± 1.2 under Pringle manzanita. These massive, well-developed stands probably

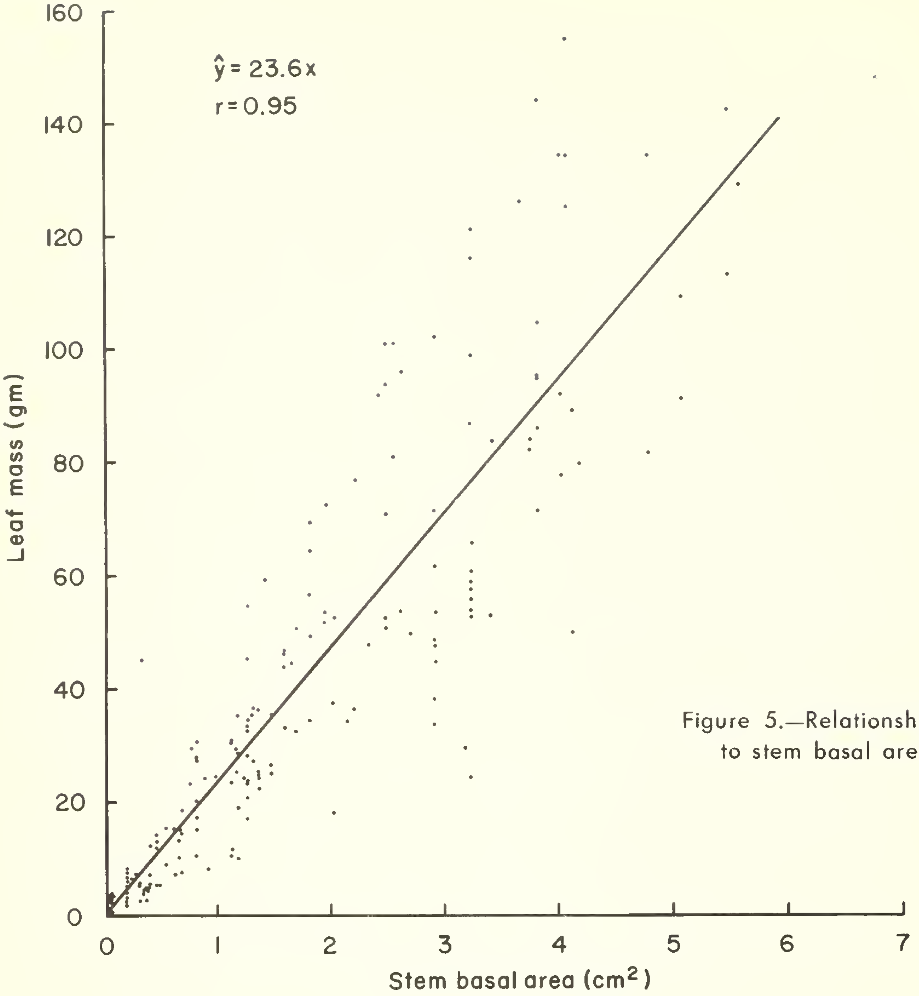

Figure 5.—Relationship of shrub live oak leaf mass to stem basal area.

represent near-maximum weight of forest floor under chaparral in the Sierra Ancha and Mazatzal Mountains.

Moisture Retention Capacity

Moisture-holding capacity of Pringle manzanita litter was significantly higher than shrub live oak litter ($P = 0.05$). Pringle manzanita litter retained 195 percent moisture content, based on ovendry weight, compared to 180 percent for shrub live oak litter. Applied to the weight of forest floor, this amounted to 5.1 and 4.8 mm depth of water, respectively, under the two types. Because litter mass was slightly greater under shrub live oak, the total water retained per unit area was not significantly different between the two communities. Little "matting" or aggregation of the litter elements occurred, even during decomposition. Moisture-holding capacity of both manzanita and shrub live oak was greater than Kittredge (1955) reported for related species in California.

Within each community, litter weight varied much more than did water retained per gram of litter, even though the communities were of uniformly high crown cover. Coefficients of variation for litter under manzanita and oak were 56 and 35 percent, respectively. Coefficients of variation for grams of water per gram of litter, on the other hand, were only 11 and 12 percent.

Field moisture capacity as determined probably represents the upper limit for rainwater held in the litter mass. Size and duration of storm, and interval between storms, of course, would directly influence the amount of precipitation retained.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-215

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S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Solar Radiation Affects Radiant Temperatures of a Deer Surface

H. Dennison Parker, Jr.,[1] and James C. Harlan[2]

Variation in the effective radiant temperature (ERT) of a deer hide, when sunlit and shaded, was measured with an infrared radiometer. The mean decrease in ERT was 18.3° C. in 120 seconds after shade was applied. The authors conclude that missions for deer detection by an airborne thermal infrared scanner should be conducted during periods of no direct-beam solar radiation, that is, sunset to dawn.

Keywords: Deer, infrared, thermal scanner, solar radiation.

The experiment discussed here was an outgrowth of a broader study of the environmental factors that affect thermal radiation from mule deer (Odocoileus hemionus hemionus) in winter,[3] as a basis for determining the detectability of these animals by an airborne thermal infrared scanner. Detection of deer by this method depends on the difference in effective radiant temperature (ERT) between the animals and their background. One factor which caused large, rapid changes in the ERT of the deer in that study was shading from various sources, including cloud passage. Abrupt decreases and increases in excess of 15° C. were observed on several occasions, apparently due to this effect.

The purpose of this experiment was to determine the magnitude and rate of change in ERT of a simulated deer surface which could occur as a result of shading.

Methods

A tanned, furred mule deer hide was used to simulate a live deer surface. It was supported horizontally 18 inches above a gravel surface, outdoors. ERT measurements were made at a distance of 38 inches with a Barnes PRT-5 Infrared Radiometer[4] aimed at a point near the center of the hide. The resulting field diameter on the deer hide was about 1.3 inches. The radiometer output was recorded continuously on a strip-chart recorder, running at 2 inches per minute.

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[2] *Graduate Research Assistant, Colorado State University, Fort Collins, when research was conducted. Harlan is now Principal Engineer, Lockheed Electronic Company, Houston, Texas.*

[3] *Parker, H. Dennison, Jr. Airborne infrared detection of deer. Ph. D. thesis, Colorado State University, Fort Collins. 186 p. 1972.*

[4] *Trade and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

A "run" consisted of a time period which began when the deer hide was abruptly shaded with a piece of plywood. The plywood was held between the sun and the deer hide approximately 8 feet from the observed portion of the hide. Shading was continued until the radiant temperature of the hide had become stable. Then the shade was removed and the ERT of the hide was monitored until stability was again reached.

Three runs were made. The investigator doing the shading remained in the same position relative to the deer hide to prevent any change in infrared radiation falling on the deer hide from surrounding objects. The air temperature beneath the hide was continuously monitored by an Atkins temperature monitoring system.

The sky was clear on the day of the test; air temperature underneath the hide varied from 2.3° to 2.5° C., and windspeed was estimated at 10 to 15 miles per hour.

Results

Effective radiant temperatures stabilized in approximately 120 seconds after shading in all three runs (fig. 1). Decreases of 19.9°, 17.2°, and 17.3° were recorded for runs 1, 2, and 3, respectively. After removal of the shade, the radiant temperatures increased at a rate similar to the decay rate and stabilized at approximately the same temperatures which existed prior to shading (fig. 2).

The small, erratic fluctuations in ERT in the chart recording (fig. 2) represent forced convective cooling caused by wind, and were more pronounced at higher ERT values. This difference in wind effect between high and low ERT values is reasonable, considering that the rate of heat transfer was proportional to the thermal gradient from the radiating surface to the air. At high ERT values, the thermal gradient between hair surface and air was greater than at low ERT values.

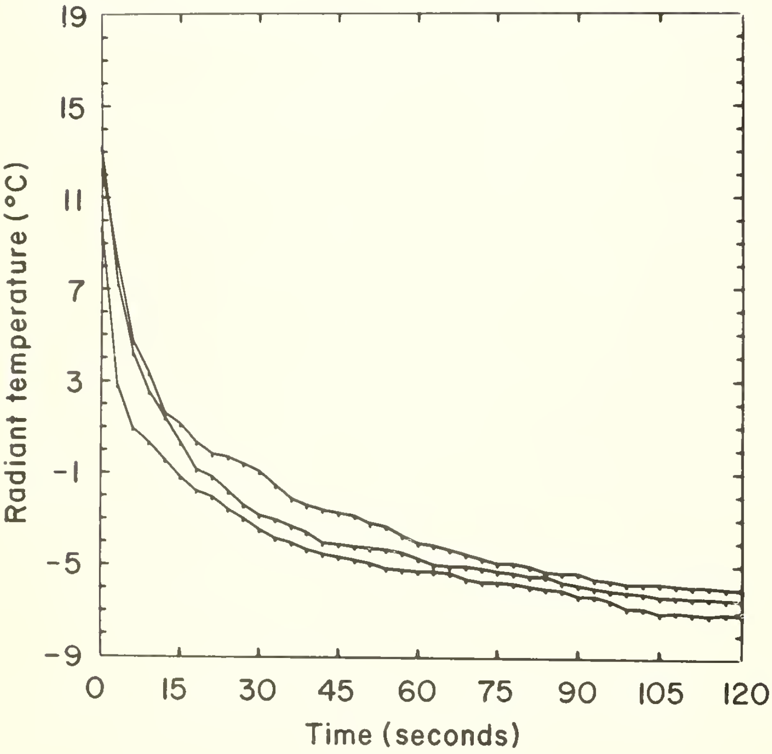

Figure 1.—Radiant temperature decay, sampled at 3-second intervals. Shade was applied at time = 0.

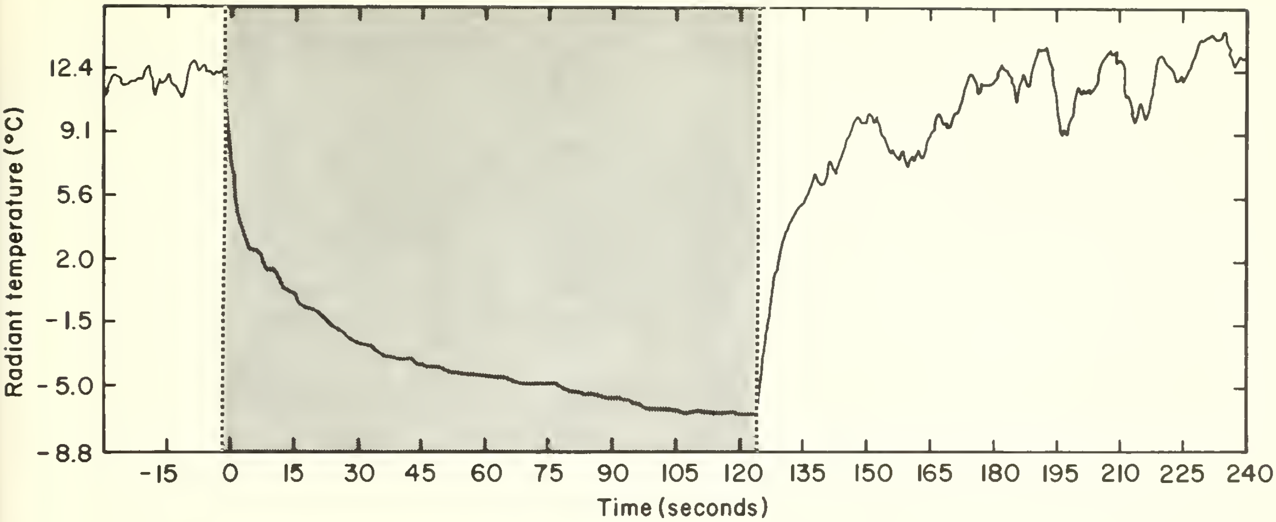

Figure 2.—Chort recording of radiant temperature far run Na. 1. Shade was applied at time = 0 and removed at time = 120 secands. Curve shapes were similar far all three runs.

Conductive heat transfer from the fur surface to the skin has been shown to occur primarily in the air trapped between the hairs.[5] The approximate quantity of energy transferred in this manner is given by:

$$H = K(\Delta T/\Delta Z) \qquad [1]$$

where

H = conductive heat transfer (cal $cm^{-2} min^{-1}$)

K = thermal conductance of the conducting medium

ΔT = temperature difference (° C.)

ΔZ = distance (cm)

If $K_{fur} \leq K_{air}$, then the thermal conductance of air, 3.58×10^{-3} cal $cm^{-1} min^{-1}$ °C.$^{-1}$, may be used for K. ΔT averaged 18° C., assuming (1) the emissivity ϵ of fur is very nearly 1.0; thus radiant temperature $\simeq$ actual temperature, and (2) skin temperature = air temperature when shaded. ΔZ was approximately 2 cm.

Using these values in equation [1] gives an initial rate of conductive heat transfer of 0.0322 cal $cm^{-2} min^{-1}$.

Radiant heat transfer is 4.2 mw $ster^{-1} cm^{-2}$ at a radiant temperature of 18° C., assuming $\epsilon = 1.0$.[6] Multiplying by 2π to get total hemispherical radiation, and converting units, the rate of radiant heat transfer is 0.3781 cal $cm^{-2} min^{-1}$.

Thus, the initial rate of conductive heat transfer is less than one-tenth the radiant heat transfer rate. Total heat transfer by each process could be obtained by integration of each rate over the 120-second time interval. Although radiation from a live deer is considerably more complex, the response of the fur layer to changing solar radiation may be reasonably expected to be similar to that shown in this experiment.

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[6] *mw $ster^{-1} cm^{-2}$ is an abbreviation for milliwatts per steradian per square centimeter, which are units for radiant power emission (milliwatts), through a unit solid angle (steradian), from a surface 1 square centimeter in area.*

Discussion

The difficulty of obtaining radiation data under cloudy conditions, with remote sensors operating in the reflective wavelength bands, is well known. This experiment demonstrates a degree of variability in emitted radiation which can occur in the longer (8 to 14 micrometer) wavelengths, as a result of shading. A quantitative, general description of this effect in terms of the various environmental influences and specific surface characteristics must await further study. However, these results confirm the existence of a shading effect large enough to be of importance in an airborne thermal infrared scanning operation.

In particular, detection of big game animals by their thermal radiation will probably depend on thermal contrasts between the animals and their background which are considerably smaller than the temperature differential found in this study due to shading alone. Therefore, in terms of the effects of solar radiation on ERT, conditions for thermal detection of wild, big game animals would appear to be optimum during those periods when solar radiation is uniform. This criterion may be met by conditions of either (1) no cloud shadow on the flight line, or (2) no direct-beam solar radiation, that is, 100 percent cloud cover, or the period from sunset to sunrise, including crepuscular hours and hours of darkness. Since shadows may be cast by environmental objects other than clouds, the latter situation is probably preferable. Night or total cloud cover is probably desirable from the standpoint of wind effect, also, since variability of deer ERT due to wind decreased under conditions of no direct-beam solar radiation.

U S D A FOREST SERVICE
RESEARCH NOTE RM-216

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KY MOUNTAIN FOREST A[illegible] EXPERIMENT STATION

Effects of Soil Type and Watering on Germination, Survival, and Growth of Engelmann Spruce: *A Greenhouse Study*

Daniel L. Noble[1]

Watering treatments affected both germination and survival; soil type affected survival only. Root elongation was significantly different between soils with adequate water, but top height and total plant dry weight were not significantly related to either soils or watering treatments.

Keywords: *Picea engelmannii,* plant soil-water relations, plant physiology, seed germination.

The amount and distribution of precipitation during the growing season are important factors affecting the germination and early survival of Engelmann spruce (Picea engelmannii Parry) (Alexander and Noble 1971). Regeneration success on the Fraser Experimental Forest in central Colorado has been better on one soil than another, however, even under similar precipitation patterns.

The study reported here was made under controlled greenhouse conditions in 1970 to supplement field observations. Germination, initial survival, and growth were compared on two soils under watering treatments selected to represent a common precipitation pattern on the Fraser Experimental Forest (Alexander and Noble 1971, U.S. Weather Bureau 1931-70).

Methods and Materials

Seed source.—Engelmann spruce seeds collected at 9,500 feet elevation in 1967 on the Routt National Forest in Colorado were used. Average laboratory germination was about 75 percent.

Soil and seeding.—Two forest soils from 10,500 feet elevation on the Fraser Experimental Forest were used. Bobtail soil, a gravelly, sandy loam, is a Sols Bruns Acides which developed in place under a mixed spruce-subalpine fir (Abies lasiocarpa (Hook.) Nutt.) lodgepole pine (Pinus contorta Dougl.) stand from gneisses and schists that were metamorphosed from granitic rock. Weathering has been slow, and as a result the soil contains a large amount of sand and gravel (Retzer 1962). Darling soil, a gravelly, sandy loam, is a Podzol developed in place under a spruce-fir stand from coarse-textured material weathered from mixed gneisses and schists.

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[1] *Forestry Research Technician, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

Each soil was screened through 4-mesh hardware cloth and thoroughly mixed. Moisture content at tensions of 1/3 and 15 bars, determined in the laboratory, were approximately 18 and 9 for the Darling soil, and 15 and 8 percent for the Bobtail soil, respectively. Mechanical analyses showed approximately 56, 34, and 10 percent sand, silt, and clay, respectively, for the Darling soil, and 54, 30, and 16 for the Bobtail soil.

Pots were soaked twice daily for 3 days before seeds were sown. Twenty seeds were carefully broadcast on the surface of each pot. All pots were then soaked again to insure that soil moisture was near saturation before watering treatments were begun. A total of 60 pots, 30 for each soil, 7 inches deep and 6 inches in diameter, were prepared.

Experimental design and treatments.—The experiment was a two-factor factorial with two soil types and five water levels, replicated six times. Soil types were arranged as a split plot with the following watering treatments randomized as main plots: 0.0, 0.5, 1.0, 1.5, and 2.0 inches monthly. Water was applied at the rate of 0.25 inch at each watering. The number of waterings and interval between each was determined by the assigned treatment.

Greenhouse environment.—Environment in the greenhouse at Fort Collins was maintained as closely as possible to average field conditions during the growing season at 10,500 feet elevation on the Fraser Experimental Forest. Air temperatures were 70° F. (± 2°) during the day and 40° F. (± 2°) at night. The photoperiod was 16 hours of natural and artificial light. The transition period of temperature changes coincided with light changes. Relative humidity varied from 20 to 30 percent during the day and 70 to 80 percent at night.

Measurements and analyses.—Number of germinating seeds, number of surviving seedlings, and cause of mortality were recorded biweekly. At the end of 24 weeks, the soil was carefully washed from the roots of all live seedlings, and the top height and root length were measured to the nearest millimeter. The tissue was then ovendried for 24 hours at 100° C. and weighed to the nearest 0.1 milligram.

Germination and survival were expressed as a percent of the number of seeds sown per pot; top height, root length, and total seedling dry weight were weighted pot means. Differences due to treatment were tested for significance by analyses of variance, with arc-sin transformation for percentage data. The means of significant effects were compared by Tukey's Test.

Results

Germination.—There were no significa differences in germination between soil type Total germination increased from 12 perce to 50 percent as the amount of water receiv increased from 0.0 to 1.5 inches per mont Additional water did not significantly impro germination (fig. 1).

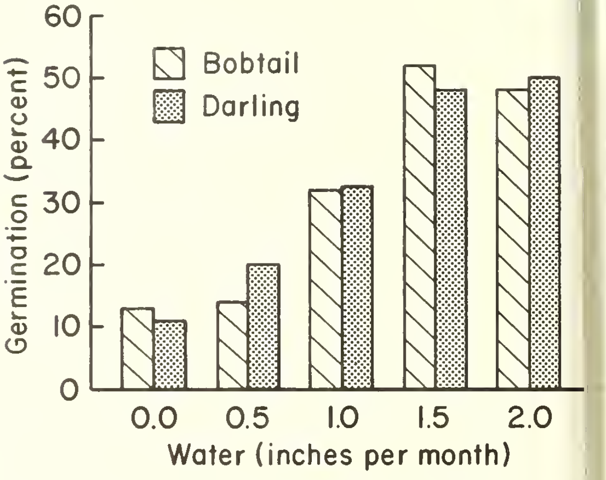

Figure 1.--Total germination in relation to soil type and watering treatment.

Germination in the unwatered treatmen ended by the second week, and was complete in the 0.5-inch watering treatment after 3 weeks Most seeds that germinated in the other treatments had emerged by the 4th week, but a fe seedlings continued to emerge for as long a 10 weeks (fig. 2). The germination pattern wa similar to that observed by Alexander an Noble (1971).

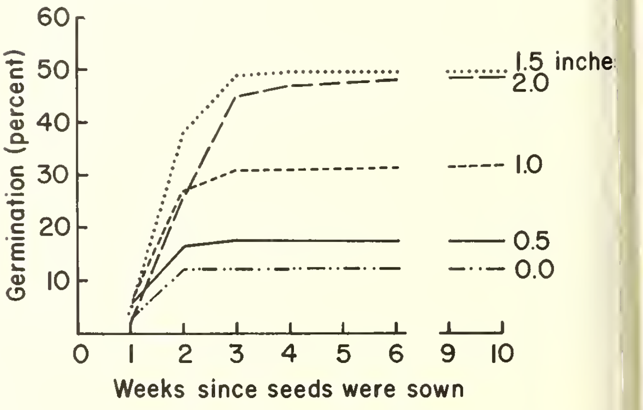

Figure 2.--Length and pattern of germination period in relation to watering treatment. (Soils were not significantly different.)

Seedling survival.—Number of seedlings surviving after 24 weeks was related both to amount of water received and soil type. In the Bobtail soils, 1.5 inches of water per month was required to sustain significant survival. In the Darling series, 1.0 inch monthly was sufficient (fig. 3).

In both soils, there was little difference in survival between the 1.5- and 2.0-inch watering treatments (fig. 3).

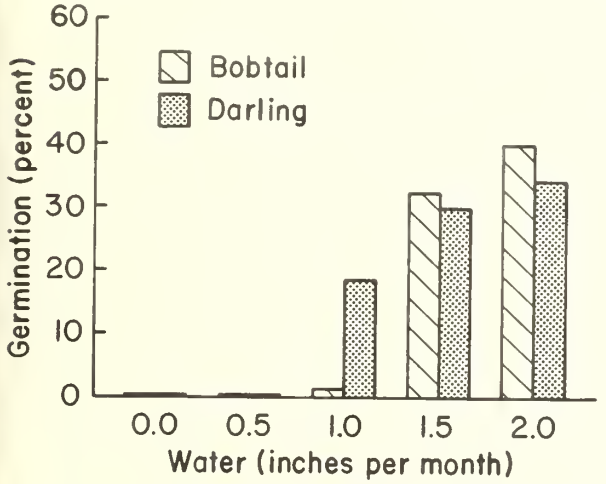

Figure 3.--Seedling survival after 24 weeks in relation to soil type and watering treatment.

Causes of mortality.—The basic difference between soils was in degree and not in cause of mortality (table 1).

1. Drought was the most important cause of seedling death in the Bobtail soil at watering treatments up to 1.5 inches, and accounted for 22 percent of the mortality in the 2.0-inch watering treatment. In the Darling soil, drought was a major factor in the 0.0- to 1.0-inch watering treatments, then dropped off rapidly to no loss in the 2.0-inch treatment.

2. Damping-off did not occur in either soil until 1.0 inch of water or more was applied per month. Two inches of water per month caused significant losses in both soils. Mortality occurred in the first 2 weeks following emergence in all watering treatments.

3. A seedling "failed to establish" if the radicle emerged from the seedcoat but did not become rooted. Possible causes may have been that seeds failed to imbibe sufficient water, did not have adequate food reserves, the soil surface was too hard for the radicle to penetrate, or any combination of these factors. Failure to establish was a consistent cause of death in the Bobtail soil at all watering levels, with the highest mortality in the 2.0-inch water treatment. The loss was serious only in the 1.5- and 2.0-inch water treatments in the Darling soil.

4. Death from a factor or factors that could not be determined was assigned to other causes.

Table 1.--Percent mortality, by cause and soil types among greenhouse-grown Engelmann spruce seedlings

Cause of mortality	Water per month				
and soil type	None	0.5 inch	1 inch	1.5 inches	2.0 inches
Drought					
Bobtail	93.8	76.5	75.7	56.5	22.2
Darling	100	95.8	82.4	28.6	0
Damping-off					
Bobtail	0	0	5.4	8.7	44.5
Darling	0	0	17.6	23.8	57.9
Failure to establish					
Bobtail	6.2	23.5	18.9	17.4	33.3
Darling	0	4.2	0	38.1	15.8
Other causes					
Bobtail	0	0	0	17.4	0
Darling	0	0	0	9.5	26.3

Seedling growth.—Top height and total plant dry weight in the 1.5- and 2.0-inch treatments — where survival was sufficient to make comparisons—were not significantly related to either soil type or amount of water. Roots in the Bobtail soil were significantly shorter (table 2), but were larger in diameter than in the Darling soil.

Table 2.--Engelmann spruce seedling growth in greenhouse by soil types and watering treatments

Growth by soil type	Water per month 1.0 inch	1.5 inches	2.0 inches
Height (cm)			
Bobtail	--	2.2	2.3
Darling	2.2	2.2	2.1
Root Length (cm)			
Bobtail	--	[1]15.1	[1]15.4
Darling	19.1	20.1	18.4
Dry Weight (mg)			
Bobtail	--	23.8	30.0
Darling	28.4	30.0	23.9

[1] Significant at the 99 percentile between soils.

Discussion and Conclusions

The greenhouse environment was more favorable for germination, survival, and growth of spruce seedlings than that likely to occur in the field. By combining data from this study with field observations, however, we can draw some inferences concerning the effect of the two soil types and various amounts of precipitation on germination and first-year seedling survival and growth.

The Bobtail soil formed a hard crust and compacted more in the greenhouse pots than did the Darling soil. Likewise, water soaked into the Bobtail soil more slowly. The crust on the Bobtail soil may explain why a consistent percent of seedlings failed to establish; the radicles had difficulty penetrating and becoming rooted.

Roots in the Bobtail soil may have encountered sufficient physical resistance from compaction so that, with only 1.0 inch of water, they could not elongate rapidly enough to maintain contact with available water. The physical resistance could also explain the shorter root lengths in the 1.5-inch and 2.0-inch watering levels. While the root diameters were not measured, it was obvious that they were not only shorter but thicker than roots from the Darling soil. The morphological difference was not reflected in root dry weights, however.

These observations suggest that soil crusting and compacting, as well as other unknown factors, influence developing seedlings. More study in the field and laboratory is needed to determine how soil characteristics and amount of water affect the ability of spruce seedlings to become established and survive.

The study showed that even small soil-related differences, when interacting with precipitation, can cause significant differences in survival and root elongation for Engelmann spruce seedlings during their first year of growth. Other weather and environmental factors also interact to affect regeneration success, however.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 217

REST SERVICE
S DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Bark Thickness and Past Diameters of Engelmann Spruce in Colorado and Wyoming

Clifford A. Myers and Robert R. Alexander[1]

Past diameter can be estimated from present diameters and radial wood growth for any desired period. Equation constants account for any periodic change in bark thickness.

Keywords: Forest measurement, tree increment estimates, tree diameter measurement, *Picea engelmannii*.

Past diameters of trees on temporary plots are used to determine periodic changes in plot basal areas and volumes. Estimates of periodic growth are useful in management planning and in the derivation of growth functions for modeling changes in forest stands.[2] Increase in diameter at breast height is the result of increase in thickness of both wood and bark. Both must, therefore, be accounted for in converting present diameters outside bark to equivalent past diameters. At least two measurements are needed for each tree, both at breast height: (1) diameter outside bark, and (2) average radial growth of wood for any desired period as measured on an increment core. Bark thickness often is not measured, since it can be estimated from relationships determined in advance from appropriate measurements on many trees.

The relationships presented below were computed from data obtained from 1,516 Engelmann spruce (Picea engelmannii Parry) located on nine National Forests in Colorado and southern Wyoming. Present diameters outside bark, measured with a diameter tape, ranged from 1.2 to 35.9 inches. Bark thickness at breast height was measured to the nearest 0.05 inch with a bark-measuring instrument at three points on each tree.

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[2] *Myers, Clifford A. 1971. Field and computer procedures for managed-stand yield tables. USDA For. Serv. Res. Pap. RM-79, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.*

The linear relationships given below apply at breast height over the range of diameters sampled. Correlation coefficients are nearly 1.0, which is usual for these relationships.

Conversion of diameter outside bark (d.o.b.) to diameter inside bark (d.i.b.):

$$\text{d.i.b.} = 0.9502\ (\text{d.o.b.}) - 0.2528 \qquad [1]$$

Conversion of diameter inside bark (d.i.b.) to diameter outside bark (d.o.b.):

$$\text{d.o.b.} = 1.0508\ (\text{d.i.b.}) + 0.2824 \qquad [2]$$

A past diameter outside bark is computed as follows:

1. Convert present d.o.b. to present d.i.b. with equation 1.
2. Subtract twice the radial wood growth from present d.i.b. to obtain past d.i.b.
3. Convert past d.i.b. to past d.o.b. with equation 2.

For efficient use in computer programs, the two relationships can be combined so all computations appear in a single expression. To do this, the right hand side of equation minus twice radial growth is substituted f d.i.b. in equation 2. The expression is the simplified. For Engelmann spruce, the result i

$$\text{Past d.o.b.} = 0.9985\ (\text{Present d.o.b.}) \quad [$$
$$-0.0168 - 2.1017$$
$$(\text{radial wood growth})$$

Table 1 gives the past diameter for each several combinations of present diameter an periodic radial wood growth. For example, present diameter is 13.5 inches and radial woo growth totaled 0.85 inch for a particular perio diameter outside bark was 11.7 inches at th beginning of the period. Interpolation can b used to obtain past diameters when presei diameters and amounts of radial growth diffe from those given in the table. Computatio using equation 3 will usually be more appropr ate. Past diameters of trees with radial growt less than 0.15 inch are merely present diametei minus twice the amount of radial growth. Fc such trees, increase in bark thickness with un increase in diameter is too small to affect dian eters to the nearest 0.1 inch.

Table 1.--Present and past diameters of Engelmann spruce in Colorado and Wyoming

Present d.b.h. outside bark	Periodic radial wood growth in inches																	
	.15	.25	.35	.45	.55	.65	.75	.85	.95	1.05	1.15	1.25	1.35	1.45	1.55	1.65	1.75	1.85
	Past d.b.h. outside bark in inches																	
1.5	1.2	1.0	0.8	0.6	0.4	0.1												
3.5	3.2	3.0	2.8	2.6	2.4	2.1	1.9	1.7	1.5	1.3	1.1	0.9	0.7	0.5	0.3			
5.5	5.2	5.0	4.8	4.6	4.4	4.1	3.9	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.3	2.0	1.8	1.6
7.5	7.2	7.0	6.8	6.6	6.3	6.1	5.9	5.7	5.5	5.3	5.1	4.9	4.7	4.5	4.2	4.0	3.8	3.6
9.5	9.2	9.0	8.8	8.6	8.3	8.1	7.9	7.7	7.5	7.3	7.1	6.9	6.7	6.5	6.2	6.0	5.8	5.6
11.5	11.2	11.0	10.8	10.6	10.3	10.1	9.9	9.7	9.5	9.3	9.1	8.9	8.7	8.5	8.2	8.0	7.8	7.6
13.5	13.2	13.0	12.8	12.6	12.3	12.1	11.9	11.7	11.5	11.3	11.1	10.9	10.7	10.4	10.2	10.0	9.8	9.6
15.5	15.2	15.0	14.8	14.5	14.3	14.1	13.9	13.7	13.5	13.3	13.1	12.9	12.7	12.4	12.2	12.0	11.8	11.6
17.5	17.2	17.0	16.8	16.5	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.4	14.2	14.0	13.8	13.6
19.5	19.2	19.0	18.8	18.5	18.3	18.1	17.9	17.7	17.5	17.3	17.1	16.9	16.7	16.4	16.2	16.0	15.8	15.6
21.5	21.2	21.0	20.7	20.5	20.3	20.1	19.9	19.7	19.5	19.3	19.1	18.9	18.6	18.4	18.2	18.0	17.8	17.6
23.5	23.2	23.0	22.7	22.5	22.3	22.1	21.9	21.7	21.5	21.3	21.1	20.9	20.6	20.4	20.2	20.0	19.8	19.6
25.5	25.2	25.0	24.7	24.5	24.3	24.1	23.9	23.7	23.5	23.3	23.1	22.9	22.6	22.4	22.2	22.0	21.8	21.6
27.5	27.2	27.0	26.7	26.5	26.3	26.1	25.9	25.7	25.5	25.3	25.1	24.8	24.6	24.4	24.2	24.0	23.8	23.6
29.5	29.2	28.9	28.7	28.5	28.3	28.1	27.9	27.7	27.5	27.3	27.1	26.8	26.6	26.4	26.2	26.0	25.8	25.6
31.5	31.2	30.9	30.7	30.5	30.3	30.1	29.9	29.7	29.5	29.3	29.1	28.8	28.6	28.4	28.2	28.0	27.8	27.6
33.5	33.2	32.9	32.7	32.5	32.3	32.1	31.9	31.7	31.5	31.3	31.0	30.8	30.6	30.4	30.2	30.0	29.8	29.6
35.5	35.1	34.9	34.7	34.5	34.3	34.1	33.9	33.7	33.5	33.3	33.0	32.8	32.6	32.4	32.2	32.0	31.8	31.6

Agriculture—CSU, Ft. Collins

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DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Treatment Height for Mountain Pine Beetles in Front Range Ponderosa Pine

W. F. McCambridge[1]

Pitch tubes and intermittent blue stain are generally found about 5 feet above the highest point where significant mountain pine beetle brood is produced; thus, chemical control can be achieved by spraying to 5 feet below the highest pitch tubes.

Keywords: *Dendroctonus ponderosae*, *Pinus ponderosa*, ethylene dibromide.

The Problem

Ponderosa pine trees infested by mountain pine beetles (Dendroctonus ponderosae Hopkins) are commonly felled and sprayed with ethylene dibromide during control programs in Colorado. Once an infested tree is on the ground, a decision must be made as to how much of it should be sprayed. One of four guidelines is frequently used: (1) Spray to a pre-set top diameter — for example, a 4-inch minimum; (2) spray to the highest pitch tube, plus 2 feet; (3) spray to the height of blue stain visible in the xylem; and (4) spray to the height of brood determined by bark examinations.

Control crews recognize certain shortcomings in these guides. Some of the more serious are: (1) Mountain pine beetles attack to no fixed upper diameter. Top diameter of infestation is variable from year to year and tree to tree of similar size. Setting a small upper diameter limit might result in considerable overspraying. (2) Spraying beyond the highest pitch tubes wastes insecticide and unnecessarily kills parasitic and predaceous insects attacking secondary beetles under thin bark. Some of these

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[1] *Entomologist, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

insects also attack mountain pine beetles. (3) *Ips* beetles also carry blue stain fungi, and frequently infest the upper portions of trees infested by mountain pine beetles. Blue stain near the upper limit of mountain pine beetle infestation occurs in sparse and isolated strips. (4) Brood at its upper limit is often found in strips and is very sparse. Treating to the height of blue stain or brood is overtreating, is time consuming because both are difficult to find, and is costly. A better guideline is needed.

The Data

Seventy-two trees infested with mountain pine beetles were climbed in June 1971 and examined for brood in relation to (1) height along the tree, (2) presence of pitch tubes, and (3) blue stain. The trees were examined in groups as found. The groups were scattered over the northern part of the Roosevelt National Forest near Fort Collins, Colorado.

Characteristics of the average infested tree were as follows:

Diameter (inches):	
At breast height	10.4
At maximum height of brood	8.0
Maximum height (feet):	
Of pitch tubes	24.3
Of brood	18.7
Difference	5.6
Standard deviation	2.4

Further analysis of these data show that, on the average, 75 percent of trees sampled will have pitch tubes **at least** 4 feet higher than the highest brood. There is an additional foot where brood is of little consequence.

Live brood (mostly adults and a few pupae) were taken from two 6- by 6-inch bark samples at each interval on each of the 72 trees. A good idea of how much brood is found near the upper limits of brood (not pitch tubes, which on the average are another 5.6 feet higher) is as follows:

Distance down from upper limit of brood (feet)	**Brood per square foot (number)**	
0	1.6	
1	4.0	
2	14.4	**Sprayed under this guide**
3	14.8	
4	25.2	
5	30.0	

Discussion

Treating trees to within 5 feet of the highest pitch tubes will prevent overtreatment and save money. The money saved will be directly proportional to the amount of insecticide saved and the cost of labor for spraying once the tree is cut and limbed. In our average tree (10.4 inches d.b.h. with Girard form class 76), the area between the highest pitch tubes (and scattered blue stain) and the highest brood is 18.8 percent of the bark area attacked by beetles. By reducing spray height the reduction in sprayed area will save about 39¢ (= 5 percent of total cost) per tree.[2] This calculation is conservative since the branches in the upper infested bole require a disproportionate amount of effort for limbing. As trees get larger, the percent of bark area which does not need spraying gets smaller. For example, if the average infested tree is 11.5 inches d.b.h., the area omitted from spray is 16.2 percent of the bark showing evidence of attack. This latter mean diameter is very realistic for infested ponderosa pines in Colorado, and in the Black Hills of South Dakota.

There is little need for concern that the few beetles escaping from unsprayed tops will continue the infestation. Their numbers, even collectively, will be relatively small. Repeated observations of control operations reveal unsprayed groups of trees within and adjacent to control areas are, by far, the chief contributors to continuance of beetle epidemics.

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[2] *Based on 1971 control cost breakdowns furnished by Colorado State Forest Service. Average cost/tree for chemical was $1.35, and 15 percent of labor cost/tree was spent applying insecticide. (Total labor cost/tree = $5.42.)*

1972

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RESEARCH NOTE RM- 219

OREST SERVICE
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CKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

An Initial Assessment of Mammal Damage in the Forests of the Southwest

L. J. Heidmann[1]

Mammal damage is a serious problem in some forests of the Southwest. All size classes of trees are affected, but the problem is most serious in plantations and stands of young trees. In addition, mammals are a major factor in preventing the establishment of regeneration on one-half million acres of nonstocked forest land in the Southwest.

Keywords: *Pinus ponderosa*, mammals, timber management.

One of the greatest problems in the management of ponderosa pine *(Pinus ponderosa)* in the Southwest is obtaining regeneration. Both natural and artificial reforestation measures have frequently been unsuccessful. Although competing vegetation coupled with drought periods at critical times have been most damaging, damage by mammals is an important factor in initial and subsequent survival of young trees (Schubert et al. 1969). Data on the extent of mammal damage are scarce, however.

In an attempt to get at least a qualitative idea of mammal damage to forests in the Southwest, a questionnaire was sent to various forest managers in the summer of 1970. Questionnaires were sent to each Forest Service Ranger District in Arizona and New Mexico, the Grand Canyon National Park, the Bureau of Land Management, the Northern Arizona School of Forestry, and the Mescalero, Navajo, Jicarilla, Southern Ute, San Carlos, Fort Apache, and Hualapai Indian Reservations. Respondents were asked to estimate how many acres of forest trees were being damaged by mammals, which mammals were responsible, and what percentage of the trees on these acres were being damaged. They were also asked, "What is your most serious mammal damage problem?"

As used here, mammal damage is defined as a significant impairment to the initial establishment and subsequent growth of trees. Occasional browsing of seedlings or twigs is not considered to be damage.

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Types of Damage and Mammals Responsible

The problem of mammal damage may begin before the cones are mature on the tree. The Abert squirrel *(Sciurus aberti aberti (Woodhouse))*, which is peculiar to the Southwest, consumes great amounts of ponderosa pine seed. This squirrel does not build caches, but cuts cones from the trees and eats the seed from July 1 to October (Pearson 1950, Larson and Schubert 1970). As much as 25 percent of the cone crop may be destroyed. During the winter months, the squirrel cuts twigs and eats the inner bark (fig. 1). Occasionally trees are so defoliated that they die.

The red squirrel *(Tamiasciurus hudsonicus)* builds cone caches in the transition zone between ponderosa pine and mixed conifer forests. The caches are helpful, however, when it is necessary to collect large amounts of seed.

Squirrels as well as mice *(Perognathus* sp., *Onychomys* sp., *Peromyscus* sp.*)*, rats *(Dipodomys* sp., *Neotoma* sp.*)*, and chipmunks, *(Eutamius* sp.*)* will eat any seeds that fall to the ground. According to Pearson (1950), it is only in exceptionally heavy seed years that there is enough seed left for natural regeneration.

Seedlings that have germinated may be killed by mice, rats, and other rodents gnawing on the stem or cotyledons (figs. 2, 3). Pocket

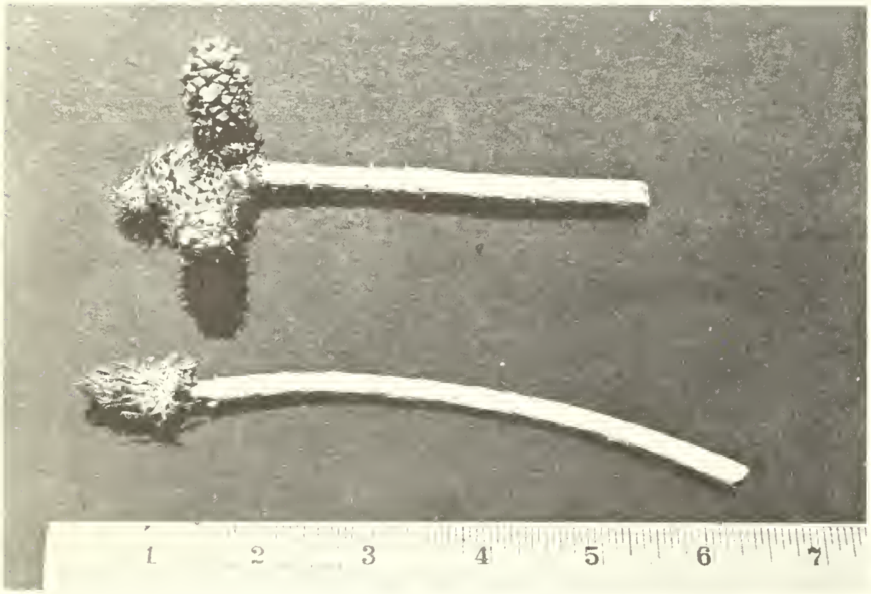

Figure 1.--Twigs clipped from ponderosa pine by an Abert squirrel.

Figure 2.--Young ponderosa pine seedling girdled by a mouse.

Figure 3.--Cotyledons clipped off from a newly germinated ponderosa pine seedling. This damage could have been caused by mice or birds.

gophers *(Thomomys* sp.*)* cause considerable mortality by girdling the tree below the ground line (fig. 4). Gophers may kill trees as large as saplings.

Rabbits *(Sylvilagus* sp.*)* and hares *(Lepus* sp.*)* feed on needles, buds, and bark of small trees. In winter they are able to reach the tops of 4- to 5-foot trees, depending on the depth of snow cover. Rabbit damage is easy to identify because of the characteristic sharp, angled cutting of the stem (fig. 5).

Figure 4.--Seedlings killed by pocket gophers.

Figure 5.--Rabbit damage to planted seedling. Smooth, slanting cut is typical of damage by rabbits and hares.

Porcupines *(Erethizon* sp.*)* may cause heavy damage in stands from seedling to pole and sawtimber size (fig. 6). Smaller trees may be killed, while larger trees are deformed so badly they are unmerchantable.

Damage from trampling and browsing by livestock occurs from the time seedlings are planted or germinated until they are 4 to 5 feet tall (fig. 7). Because livestock can destroy all of the trees in a plantation, they should be excluded for several years, preferably until the trees are out of reach of the animals.

Large mammals such as mule deer *(Odocoileus hemionus)* and elk *(Cervus canadensis)* may also browse trees severely. Browsing usually results in a reduction of growth and poor form, and quite often in death of the tree. Browsing by these animals can be distinguished from rabbit clipping by the jagged appearance of the stem, because these mammals lack upper incisors. When trees are browsed repeatedly it may take several decades before they outgrow the reach of the mammals (fig. 8).

Figure 6.--Porcupine damage in crown of a young pole-sized ponderosa pine.

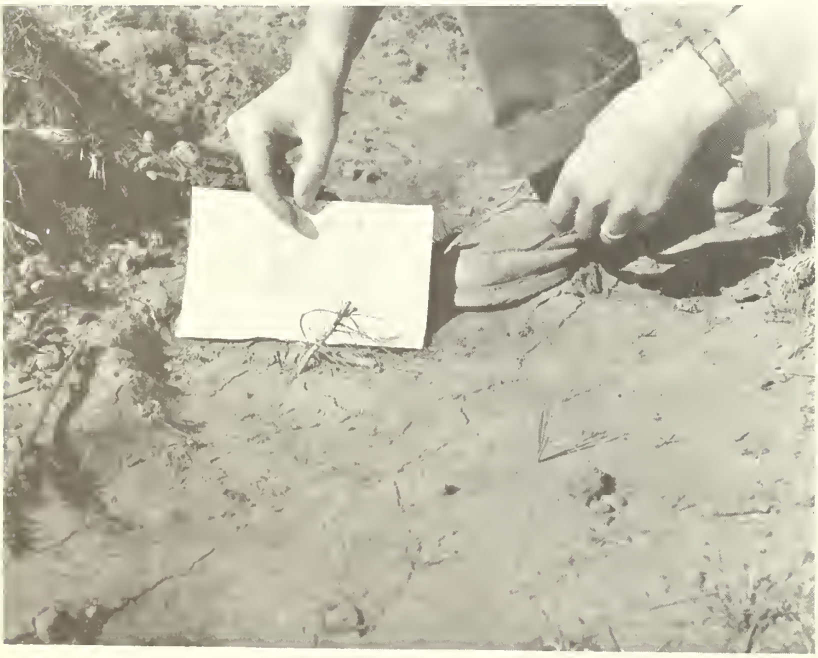

Figure 7.--Ponderosa pine seedling browsed and trampled by cattle. Over 90 percent of the trees in this plantation were browsed.

Figure 8.--Group of ponderosa pine trees which have been repeatedly browsed by deer. All trees in the photograph except the sawtimber in the background are the same age.

Results from the Questionnaire

Over 1 million acres of commercial forest in the Southwest are subject to mammal damage (table 1). Most damage occurs on the 7.5 million acres of commercial ponderosa pine, but smaller areas in mixed conifer stands are also affected. The problem appears to be much more severe in New Mexico than in Arizona. More than half the Forest Service Ranger Districts in New Mexico reported mammal damage problems, compared with approximately one-fourth of the Districts in Arizona. Over 800,000 acres in New Mexico are affected, compared with slightly less than 300,000 acres in Arizona. The most extensive acreages involved in both States support sapling and pole stands, where damage is caused primarily by porcupines (tables 1, 2). Over 600,000 acres of sapling and pole stands are affected, while a third of a million acres of reproduction and a quarter of a million acres of sawtimber are involved.

On the Navajo Indian Reservation, about 100,000 acres of reproduction are subject to damage by sheep. On all other regeneration areas of the Southwest, cattle and sheep can be detrimental to seedling establishment, especially during the first few years after seeding or planting.

On several questionnaires, mice and voles were blamed for regeneration failures. On the Cuba Ranger District of the Santa Fe National Forest in New Mexico, voles destroyed 50 acres of planted stock in 1968. On the Sacramento District of the Lincoln National Forest, also in New Mexico, 55 percent of a tubeling plantation was destroyed by mice.

In Arizona, the most extensive damage in regeneration areas was attributed to gophers and other rodents. On the Chevelon District of the Sitgreaves National Forest, approximately 25,000 acres of regenerated areas are affected by these mammals.

Most of the districts reporting damage stated that from 0 to 25 percent of the trees were affected. On several areas, however, damage was much higher. On the Sacramento District of the Lincoln it was reported that, of 10,000 acres of reproduction, from 50 to 75 percent of the trees were damaged (table 1).

The percentage of questionnaires returned was high. Of the 76 Forest Service Ranger Districts in Arizona and New Mexico, all but seven responded. These seven districts are composed mainly of nontimbered areas. The response from the other agencies was also excellent.

Table 1.--Areas reporting damage and acres of damaged trees, by size classes and percent of damage, in Arizona and New Mexico

Reporting unit	Reproduction			Saplings and poles			Sawtimber			Total, all classes
	0-25%	25-50%	50-75%	0-25%	25-50%	50-75%	0-25%	25-50%	50-75%	
	Acres									
ARIZONA										
(National Forests)										
Tonto										
Payson District	1,000	--	--	--	--	--	--	--	--	1,000
Apache										
Luna	200	--	--	100	--	--	--	--	--	300
Alpine	200	--	--	--	400	--	100	--	--	700
Prescott										
Thumb Butte	300	--	--	--	--	--	--	--	--	300
Sitgreaves										
Chevelon	25,000	--	--	--	--	--	--	--	--	25,000
Lakeside	500	--	--	--	--	--	--	--	--	500
Coronado										
Safford	--	--	--	--	2,000	--	--	--	--	2,000
Kaibab										
Chalendar	50	--	--	--	--	--	--	--	--	50
Williams	200	--	--	--	--	--	--	--	--	200
Coconino										
Blue Ridge	--	--	500	--	--	--	--	--	--	500
Long Valley	--	200	--	100	--	--	--	--	--	300
(Northern Arizona University)										
School of Forestry Forest	--	50	--	--	--	2,000	--	--	--	2,050
(Indian Reservations)										
Navajo	50,000	--	--	50,000	--	--	--	--	--	100,000
San Carlos	--	--	--	--	--	--	200	--	--	200
Fort Apache	--	--	--	100,000	--	--	40,000	--	--	140,000
Total	77,450	250	500	150,200	2,400	2,000	40,300	--	--	273,100
NEW MEXICO										
(National Forests)										
Cibola										
Mountainair	--	--	--	4,800	--	--	4,800	--	--	9,600
Magdalena	1,000	--	--	500	--	--	--	--	--	1,500
Lincoln										
Smokey Bear	200	--	--	--	--	--	--	--	--	200
Mayhill	--	450	--	--	--	--	--	--	--	450
Sacramento	--	--	10,000	5,000	--	--	--	--	--	15,000
Gila										
Beaverhead	1,500	--	--	--	--	--	--	--	--	1,500
Wilderness	--	--	--	50	--	--	--	--	--	50
Reserve	--	200	--	--	--	--	--	--	--	200
Santa Fe										
Coyote	50	--	--	--	--	--	--	--	--	50
Cuba	--	--	150	4,000	--	--	--	--	--	4,150
Jemez	50	--	--	--	--	--	--	--	--	50
Pecos	25,000	--	--	50,000	--	--	50,000	--	--	125,000
Carson										
Penasco	--	--	--	700	--	--	--	--	--	700
El Rito	--	--	--	[1]174,250	--	--	--	--	--	174,250
Jicarilla	--	--	--	5,000	--	--	5,000	--	--	10,000
Taos	--	1,500	--	5,000	--	--	4,000	--	--	10,500
Tres Piedras	--	--	--	120,000	--	--	--	--	--	120,000
Questa	200	--	--	--	--	--	--	--	--	200
(Indian Reservations)										
Navajo	50,000	--	--	50,000	--	--	--	--	--	100,000
Jicarilla	[2]50,000	--	--	50,000	--	--	--	150,000	--	250,000
Total	128,000	2,150	10,150	469,300	--	--	63,800	150,000	--	823,400

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[1] Includes damage to reproduction that was not separated out.

[2] Percent of trees damaged not reported.

Table 2.--Mammals causing damage and acreage affected

Mammals	Arizona	New Mexico
	Acres	
Deer and elk	600	20,050
Livestock	51,000	50,200
Porcupine	192,850	728,150
Mice	100	19,450
Other rodents	[1]26,450	50
Bear	2,000	0
Rabbits	100	5,500
Total	273,100	823,400

[1] Most of this damage attributed to gophers and other rodents, which affect 25,000 acres of reproduction on Chevelon District, Sitgreaves National Forest; also includes small amount of damage by beaver.

Discussion

The purpose of this report is not to claim that a million acres of forest in the Southwest are being destroyed by mammals, or that drastic control measures are needed. Rather, it is to draw attention to the fact that, in many instances, mammal damage must be considered in forest management.

This survey does indicate that damage by mammals is a problem in the forests of Arizona and New Mexico. The questionnaire suggests that a third of a million acres of reforested area is affected by mammal damage. There are, however, another half million acres of cutover and burned land in the region that need reforestation (Schubert et al. 1970). One of the principal reasons that regeneration is lacking on these areas is attrition by mammals (Pearson 1950). Most of the tree seed is consumed by rodents before it can germinate. The seedlings are then subject to attack by all of the mammals mentioned.

Damage to saplings and poles, although occurring over an area of 600,000 acres, is probably not as serious a threat as is indicated by the survey. Many districts reported that the problem is more or less endemic and generally widely scattered. There are localized areas, however, in which porcupines cause heavy damage by girdling all of the trees in a stand.

Sawtimber is probably damaged less severely than the other tree classes since damage is usually limited to the upper crown, and trees are seldom killed.

Obviously, a survey of this type is affected by the biases of the various observers. One Ranger District, for instance, reported that it had no mammal damage problems. Yet the author has conducted numerous planting studies on widely scattered areas of that District, and almost all of them have been partially to heavily damaged by elk, deer, mice, porcupines, gophers, and rabbits, singly or in combination.

In many cases it has not been recognized that mammals are a hindrance to regeneration, since very little effort has been made in the Southwest to reforest nonstocked areas. When an attempt is made to regenerate these areas, the mammal problem is soon discovered.

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U S D A FOREST SERVICE
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OREST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Mulching Improves Survival and Growth of Cercocarpus Transplants[1]

H. W. Springfield [2]

Two-year-old plants of *Cercocarpus montanus*, (true mountainmahogany) were planted by three methods on sites prepared three ways, on a semiarid pinyon-juniper area in northern New Mexico. Two years later, plants mulched with black plastic had survived and grown better than those planted in basins. Plants in large basins survived better but were essentially the same size as plants in small basins. Best growth, by far, resulted from using plastic mulch on a chemically prepared site, and was attributed to additional soil moisture and reduced weed competition.

Keywords: *Cercocarpus montanus*, plant physiology, plant water relations.

Because it is palatable and nutritious, true cercocarpus (Cercocarpus montanus) — also known as true mountainmahogany — is a desirable shrub for revegetating western ranges. This species is relatively difficult to establish by direct seeding, however, because the seedlings are susceptible to drought and frost (Plummer et al. 1968). An alternative to seeding is transplanting. The chances of successful establishment, particularly on critical areas, are much improved by planting 1- or 2-year-old nursery-grown plants.

In New Mexico, additional moisture and control of competing vegetation improved survival and growth of fourwing saltbush (Atriplex canescens) transplants (Springfield 1970). Planting in basins and applying mulches gave the best results.

Investigators in other regions have found mulching improves the survival and growth of tree seedlings (Bowersox and Ward 1970, De Byle 1969, Loewenstein and Pitkin 1970). Of the many mulches tried, one of the most effective is black polyethylene; it conserves soil moisture and suppresses unwanted vegetation.

The purpose of the experiment reported here was to determine the effects of different methods of site preparation and planting on survival and growth of cercocarpus transplants.

Methods

Plants used were grown for 2 years in 1-gallon containers in a lathhouse at Santa Fe, New Mexico. Seeds came from Pinabetosa Mesa, near Coyote, New Mexico. All plants were pruned to a height of 7 inches and crown diameter of 4 inches at the time of planting. Although the soil was moist, 1/2 gallon of water was applied to each plant the day of planting (August 11, 1969).

The transplants were arranged in a split-plot design. Main plots consisted of methods of site preparation: (1) none, (2) rototilled in June 1969, and (3) sprayed with dalapon in June 1969, at the rate of 10 pounds acid equivalent per acre. Dalapon is a sodium salt of dichloropropionic acid, applied in water solution to control grasses. Subplots were methods of

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[1] *Study conducted in cooperation with the New Mexico Department of Game and Fish under the Federal Aid to Wildlife Restoration Act, Pittman-Robertson Research Project W-109-R, "Range Revegetation Investigations."*

[2] *Range Scientist, Rocky Mountain Forest and Range Experiment Station, located at Albuquerque, in cooperation with the University of New Mexico; Station's central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

planting: (1) small basin, 6 inches in diameter, 2 inches deep, (2) large basin, 18 inches in diameter, 4 inches deep, and (3) plastic mulch, 4-mil black polyethylene, 36 inches square with a slit in the middle for the transplant, and the edges held in place with soil and rocks. About 4 square feet of exposed plastic surface surrounded each transplant.

The experimental site, 8 miles west of Santa Fe, is typical of the drier portions of the pinyon-juniper woodland. Elevation is 6,400 feet; annual precipitation averages 12 inches, a third of which falls October through March. Herbaceous vegetation consists mainly of blue grama (*Bouteloua gracilis*), galleta (*Hilaria jamesii*), ring muhly (*Muhlenbergia torreyi*), and sand dropseed (*Sporobolus cryptandrus*). Soil characteristics are as follows:

Depth (Inches)	**Texture**	**pH**
0-4	sandy loam	7.2 noncalcareous
4-11	clay loam	7.6 noncalcareous
11-16	silty clay loam	8.0 calcareous
16-27	sandy clay loam	8.0 calcareous

Precipitation was recorded in a seasonal storage gage at the site during the study:

	Inches
August 11 to October 17, 1969	4.13
October 17, 1969 to May 21, 1970	4.56
May 21 to August 14, 1970	4.70
August 14 to October 20, 1970	1.50
October 20, 1970 to May 4, 1971	2.96
May 4 to August 13, 1971	6.20

The second 12 months were appreciably drier than the first 12 months after planting, especially the late summer and fall of 1970.

The height and crown diameter of each plant were measured to the nearest inch in September 1971. Size is expressed as height times diameter.

Results

Survival

Survival was best — 100 percent — where plants were mulched with black plastic (table 1). Survival was poorest for plants in small basins. All plants in large basins survived the first year; mortality during the second year after planting probably was due to the drier weather that year.

Although all transplants in small basins on prepared sites survived the first year, half of them died the second year on mechanically prepared (rototilled) sites. High losses such as these, particularly on prepared sites, are not easily explained. Rototilling in some way may have adversely affected the moisture-holding characteristics of the soil. Also, plants of Russianthistle (*Salsola kali*) and sand dropseed invaded rototilled areas and competed with the shrub transplants. Competition from the invaders was greater the second year. In contrast, very few herbaceous plants invaded the chemically treated areas. Moreover, the perennial grasses killed in place by the dalapon remained on the surface and functioned as an organic mulch, protecting the soil against moisture losses.

Table 1.--Survival and size of cercocarpus transplants 2 years after planting, by planting method and site preparation[1]

Site preparation and planting method	Survival 1st year	Survival 2nd year	Height (H) 2nd year	Crown diameter (D) 2nd year	HD index 2nd year
	Percent	Percent	Inches	Inches	
None					
Small basin	50	33	8.0c	4.5d	36d
Large basin	100	83	8.8c	4.6d	40d
Plastic mulch	100	100	10.5bc	6.7c	70c
Chemical (dalapon)					
Small basin	100	83	10.6bc	5.0cd	53cd
Large basin	100	100	10.7bc	5.8cd	62cd
Plastic mulch	100	100	16.3a	11.0a	179a
Mechanical (rototill)					
Small basin	100	50	10.3bc	4.7d	48cd
Large basin	100	67	10.8bc	6.0cd	65cd
Plastic mulch	100	100	12.2b	8.8b	107b

[1] Means within a column followed by the same letter do not differ significantly at the 5% level.

Growth

Plants mulched with black plastic consistently grew larger than those in basins, regardless of method of site preparation (fig. 1). Plants in both the large and small basins, on the other hand, were nearly the same size.

One combination of cultural methods stands out over all the rest — using plastic mulch on a chemically prepared site (table 1). Transplants in this treatment combination grew significantly taller and wider than all others. This particular combination was almost 100 percent effective in controlling competing grasses. Rototilling, while appreciably better than no site preparation, was less effective than spraying with dalapon. On unprepared sites, grass competed with the shrub transplants even where mulched. Grass plants grew up through the slits in the plastic, and around the edges of the basins and plastic alike.

Unmulched plants that survived on unprepared sites were practically the same size in 1971 as in 1969. Increases in height and crown diameter of plants in small and large basins on prepared sites varied from slight to moderate.

Discussion and Conclusions

The main difference between the small and the large basins was the capacity to impound water. Basins should be fairly large to provide sufficient moisture for cercocarpus transplants, under the conditions that prevailed near Santa Fe. Furthermore, the results show that — to achieve maximum survival — mulching is needed to make additional moisture available to the transplants.

Mulching with black plastic definitely improved the survival and growth of cercocarpus transplants. The main benefit from the plastic

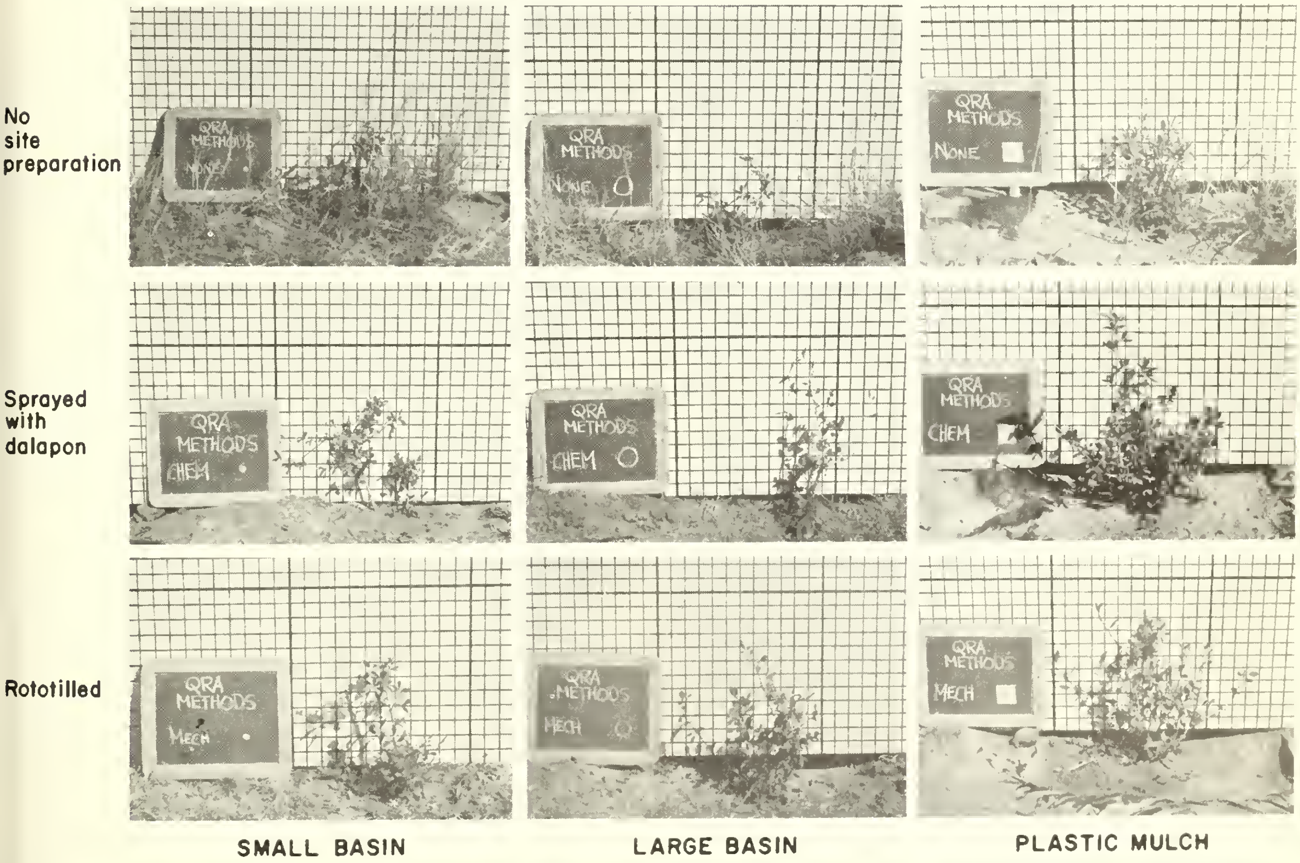

Figure 1.--After 2 years in the field, plants mulched with black plastic showed best survival and growth.

probably was conservation of soil moisture. For example, in Nevada (De Byle 1969), the surface foot of soil under a 3-foot-square sheet of 4-mil black polyethylene contained 4.1 percent more moisture than bare soil, which was near or at the wilting point by midsummer.

In our experiment, the plastic mulch square functioned somewhat as a miniature "trick tank." The sheet of plastic sloped down from the sides so that rain water was caught and funneled to the slit in the center. Consequently the transplant received most of the water that fell on the exposed plastic.

Another important function of the plastic was suppression of weeds. Although a few Russianthistle and sand dropseed plants became established in the center and around the edges, the plastic effectively prevented growth of most weedy species.

The plastic worked well, but any opaque material that shades out competing plants might be effective if it is at least 2 feet square and installed before soil moisture is depleted, according to results from Oregon (Hunt 1963).

The black plastic may also have affected soil temperatures. Studies have shown that soil temperatures under black polyethylene will be slightly higher and fluctuate less from day to night than under bare soil (Waggoner et al. 1960). At midday the black film itself may be as much as 14°C warmer than bare soil, but the soil is only 2° to 3°C warmer due to insulating air spaces between the film and the soil.

The cost of mulching with plastic was not determined in our experiment. Obviously, hand installation of plastic sheets around individual plants is time consuming and costly. More efficient, economical methods are available for applying plastic mulches in large-scale operations on relatively level terrain. For harsh or critical areas, however, intensive methods are required. Spot mulching coordinated with spot seeding or spot transplanting has been suggested for such sites (Springfield 1971). In Israel, spot mulching (polyethylene, 40 cm^2) together with spot watering (2 to 3 liters per spot at planting time) is recommended to reduce mortality and insure vigorous growth of pine seedlings (Gale and Poljakoff-Mayber 1970).

Whatever the cost, it must be balanced against the risks of failure and the costs of replanting by other methods. Other considerations are that plants not only survive better but make better growth when mulched. Therefore the plants reach a functional or usable size more quickly, whether planted for forage, soil protection, or esthetics.

Still another consideration is how long the plastic mulch will last. At several locations in New Mexico, 4-mil black polyethylene squares have remained intact 5 years. In our experience, black plastic has been more effective than straw or liquid petroleum-base mulches for suppressing weeds. No comparisons were made, but 6- or 8-mil polyethylene probably would last longer and be somewhat easier to install than 4-mil.

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U S D A FOREST SERVICE
RESEARCH NOTE RM- 221

REST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Pressure Bomb Measures Changes in Moisture Stress of Birchleaf Mountainmahogany after Partial Crown Removal

C. J. Campbell and Charles P. Pase[1]

The pressure-bomb technique detected highly significant changes in plant-moisture stress of mountainmahogany following 41 percent or more leaf-mass removal, but no significant reductions in stress when leaf mass removed was 36 percent or less.

Keywords: Pressure bomb, plant-moisture stress, *Cercocarpus betuloides*.

Modification of chaparral cover by burning, chemicals, or mechanical treatments is currently being tested on potential water-harvesting sites in the Southwest. A few public and private agencies are already manipulating vegetation over large areas, on the basis of present research findings (Pase and Ingebo 1965, Hibbert 1971).

Land managers usually attempt to reduce the original chaparral cover by 100 percent, but actual kill often is 60 percent or less. To achieve total kill or high cover reduction of the more undesirable shrubs and trees would substantially increase costs of equipment, labor, and/or chemicals. The temptation has been to treat more areas rather than to increase shrub kill to some as-yet-unknown optimum level. From a water-yield standpoint, however, is it advisable to seek moderate cover reduction over large areas, or to attempt complete vegetation control on smaller acreage? To answer this question explicitly is beyond the scope of this study; to do so, we would have to know the quantity of water residual plants use after partial crown removal or reduced competition. Evapotranspiration measurement under field conditions at best is subject to many errors. Some alternate, rapid method or "indicator" is needed to determine relative changes in plant-water status to help land and watershed managers evaluate local conditions and prescribe management alternatives. Our study was designed to determine: (1) if the pressure-bomb technique is suitable for monitoring changes in a plant's internal moisture stress following crown reduction, and (2) percent of crown removal necessary to affect the internal moisture stress and, by inference, soil-moisture conditions surrounding plant roots.

Literature

Considerable work has been reported in recent years on techniques for determining moisture stress in plants. Use of a pressure bomb (Scholander et al. 1964, 1965; Boyer 1967 a, b; Kaufman 1968) appears to be an effective field and laboratory method for determining an index of leaf-water potential and internal water stress of some plants. The technique consists of placing a leafy shoot, or single leaf, inside a steel chamber with the cut end exposed to the atmosphere. Pressure of dry nitrogen is increased within the chamber until xylem sap begins to bubble out from the cut end, at which time the pressure is recorded. This technique is particularly suited to field conditions because of rapidity of measurements, and low cost and dependability of equipment (Waring and Cleary 1967). Because the pressure needed

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to force water from leaf cells to the cut xylem surface is basically a function of leaf-water potential (Boyer 1967b), predawn pressure-bomb readings can be considered as an index to soil-moisture availability within the root zone.

Bomb measurements are influenced by osmotic potential of the xylem sap, resistance to xylem movement of water, loss of water to voids in the xylem, the rate nitrogen is released into the pressure chamber, precision of the low-pressure gage, and elapsed time between twig removal and bomb reading. Even with these sources of error, a high degree of consistency between successive readings is usually characteristic of the bomb technique because the internal plant-water status tends to integrate the effects of myriad environmental factors. For example, if soil moisture is limiting but atmospheric stress is low, then the bomb reading will also be relatively low. A change of either parameter, however, will cause the bomb reading to change. Other environmental influences such as vapor-pressure deficit, wind, and temperature, plus phenology and physiology are integrated into every bomb reading.

Results of one study on Douglas-fir (*Pseudotsuga menziesii*) indicated soil-moisture stress readings on a single tree usually varied no more than ± 2.5 atmospheres. Under such conditions, readings between trees may vary 10 atmospheres (Waring and Cleary 1967). However, bomb data are not repeatable with the same degree of consistency within and among all species; therefore, a precursor to any "bomb" study is species selection.

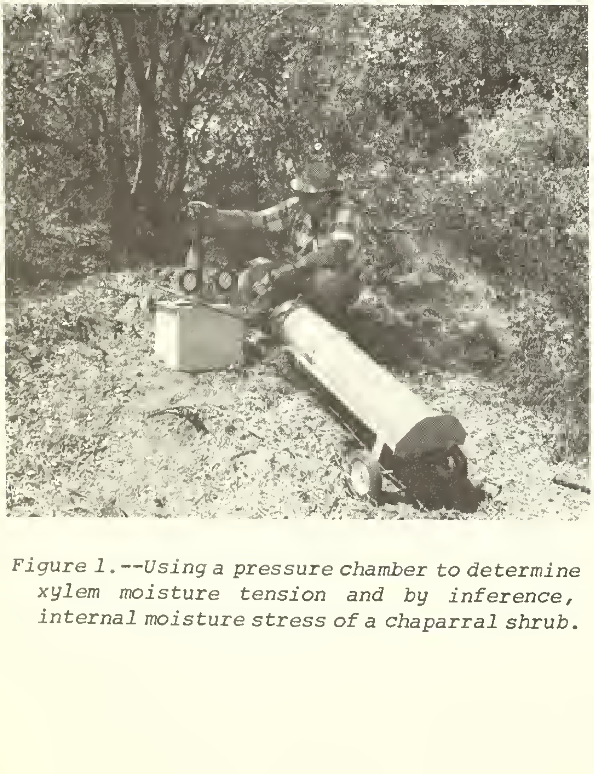

Figure 1.--Using a pressure chamber to determine xylem moisture tension and by inference, internal moisture stress of a chaparral shrub.

Methods

The pressure-chamber technique was used in our studies to determine diurnal changes in moisture stress as a result of crown reduction (fig. 1). Ten mature birchleaf mountainmahogany (*Cercocarpus betuloides* Nutt.) shrubs between 7 and 10 feet tall were selected on an upland granitic soil on the Three Bar watersheds in central Arizona. Plants were rather uniformly spaced between 10 and 15 feet from codominant species of shrub live oak (*Quercus turbinella* Greene). Two sets of "calibration" bomb readings were taken on all 10 mountainmahogany shrubs on June 13 and 24, 1968, before the summer monsoon season began, to determine relationship between controls and plants to be treated (fig. 2). Each set consisted of several independent readings under predawn, afternoon, and night conditions on each shrub. During each "run" duplicate measurements were made on each plant. On July 25, crown mass was reduced by clipping stems at the root crown on random pairs of plants by an estimated 20, 40, 60, and 80 percent. One pair was left undisturbed as a control. Stems and leaves were ovendried and weighed.

After a 2-week period for the treated plants to become stabilized, bomb readings were taken throughout several 24-hour periods for 5 months from all 10 plants. Residual crowns were then clipped and weighed on December 10, 1968. Actual leaf-mass reductions were found to be 22, 36, 41, and 66 percent; crown-mass reductions including stems were 23, 39, 49, and 69 percent. Regrowth rates of treated and control plants were not determined, but observations indicated little differences in regrowth between treatment types, perhaps because of the unusually dry conditions.

Leaf subsamples were taken from harvested plants to determine leaf area-to-weight ratios. The mean leaf area-to-weight ratio found was 49.5 ± 4 cm^2/gm. The consistency of the data indicated leaf area also could be used to evaluate treatment effects on mountainmahogany in conjunction with bomb data.

Water content of turgid leaves was initially taken to determine plant-water status sequential to bomb readings. Leaves were floated on water and maintained at a constant temperature until the water deficit existing at the time of sampling was eliminated. However, there was no statistical correlation between plant-moisture stress and leaf water content. Bomb values reflect small changes in environmental stresses on a plant within minutes; however, a degree of equilibrium is unlikely to occur until well into the night. Conversely, leaf water content measurements are insensitive to small changes in environmental stress.

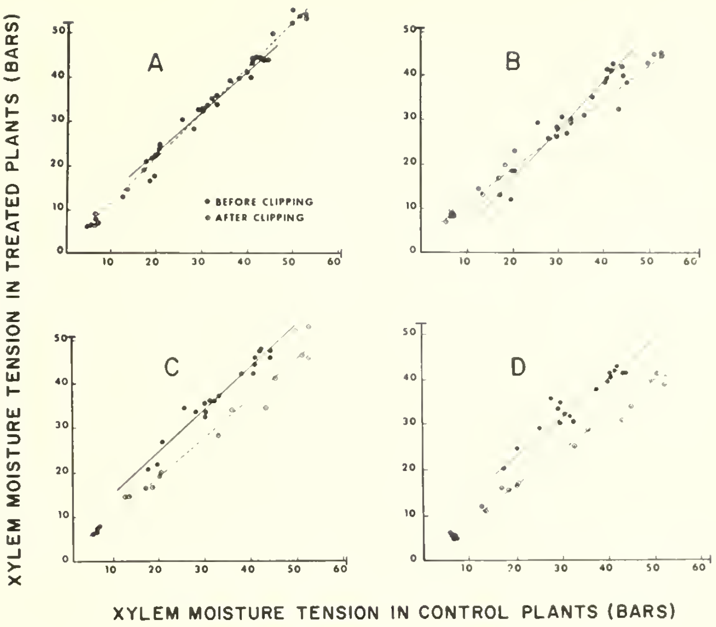

Figure 2.--Moisture tensions between two control plants, and plants with leaf mass reduced: A, 22; B, 36; C, 41; and D, 66 percent.

When mountainmahogany is under high stress, elapsed time between twig removal and the bomb reading is a very important source of error. In this study, therefore, we standardized a 1-minute lapse between twig removal and beginning of pressure application, regardless of anticipated plant stress. To eliminate other sources of mechanical errors, we preset the nitrogen inflow valve at 5 pounds per second, and used test gages with a precision of ± 2 pounds to indicate applied pressure.

Results and Discussion

The highest plant-moisture tension (55 bars) was recorded at midafternoon, but this value decreased to approximately 30 bars before midnight where it remained until sunup the following morning. Typically, the plant-moisture tension became stabilized by midnight. The soil-moisture demand determined the rate that tension decreased from late afternoon until midnight. The more crown removed, the faster the plant tension decreased from late afternoon until evening. Predawn bomb readings throughout the study period indicated a slight but not appreciable difference in available soil water between treated and untreated plants. Evidently, soil-water storage diurnally replenished these deep-rooted plants' demand for water throughout the study period.

The soil on the study site is Barkerville loamy coarse sand; it is nearly structureless, with decomposed and weathered coarse-grained granite extending to great depth. Regolith depths commonly exist to 40 feet as determined by seismic soundings. A 13-foot-deep soil trench near the study site indicated chaparral plant roots penetrate beyond this depth, where they are mostly confined to joint planes and crevices in the weathered granite. Road cuts indicate roots of these same chaparral species frequently penetrate to 30 feet. Consequently, relatively shallow soil-moisture measurements serve as indicators of soil-moisture storage in any given column, but do not necessarily indicate the source or quantity of water available to any particular plant or community. Soil-moisture values are also difficult to evaluate in terms of plant-water requirements because water requirements and use change with respect to plant growth cycles and environments. Also, and just as important, water limiting to one plant or species may be adequate for survival and growth of another. Plant-moisture stress reflects this unapparent discrepancy between the amount of soil moisture and plant-water demand, whereas soil-moisture measurements do not. The possible correlation between soil moisture and plant-moisture stress is being investigated in a later study.

Moisture tension was reduced in an "S" shaped curve following reductions expressed in either leaf or total crown mass of mountainmahogany (fig. 3). Plant-moisture stress showed the greatest rate of decrease when leaf or crown mass was reduced between 30 and 50 percent. Plant-tension reduction following leaf-mass removal above 70 percent cannot definitively be determined, but it appears from figure 2 that plant tensions would be reduced approximately 9 to 10 bars and no more.

When day and night data before and after treatment are compared by a regression analysis, plants with 22 percent leaf mass removed had an actual average tension of 23.7 bars. Without treatment these plants would have had a predicted 24.3 bars average tension. The treatment effects on moisture tension were nonsignificant. Predicted changes in plant-moisture tensions are based on bomb data collected on all plants during the calibration period.

Plants with 36 percent leaf mass removed had 30.4 bars average tension, compared to a predicted tension of 33.2 bars if the treatment had not been performed. This reduction in tension indicated a highly significant change occurred following treatment, but insufficient data during the calibrating period prevent firm conclusions (fig. 2).

After a 41 percent leaf-mass reduction, post-treatment tensions differed highly significantly from a predicted 26.3 bars to an actual 20.6 bars. Even more obvious is the change in plant-moisture tension after 66 percent of leaf mass is removed (fig. 2D). Predicted tensions of the plants would have averaged 26.3 bars if no treatment had occurred; actual tensions averaged 17.8 bars — a decrease of about 8 bars.

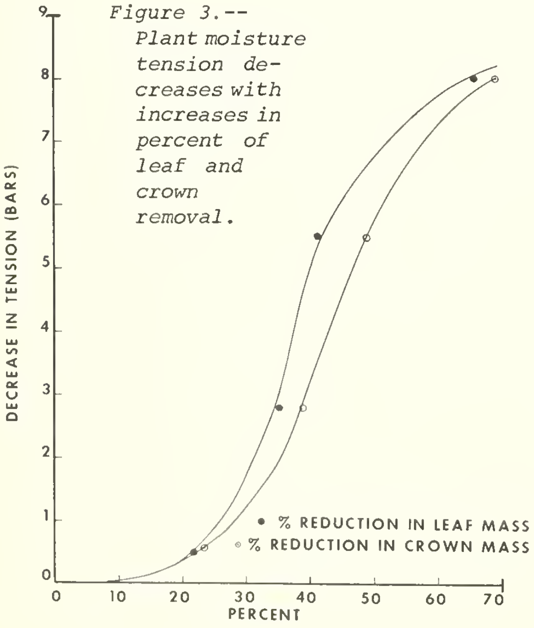

Figure 3.--Plant moisture tension decreases with increases in percent of leaf and crown removal.

From these data it seems reasonable to assume treatments that reduce leaf mass of mountainmahogany plants by about 35 percent do not measurably influence plant-water relationships. Our data indicate but do not necessarily prove that, in areas where 40 to 70 percent of the shrub crown mass has been removed, residual plants have lower moisture stress, probably because demand for soil water is reduced. Thus, total water use of the plant is probably less than before treatment, simply because of reduced evaporative leaf surfaces. We can logically assume soil moisture is more available in the immediate vicinity of these plant roots. In our study areas where competitive species were not removed, root systems of surrounding plants probably withdrew soil water normally removed by the treated mountainmahogany.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-222

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CKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Accuracy of Determining Mountain Pine Beetle Attacks in Ponderosa Pine Utilizing Pitch Tubes, Frass, and Entrance Holes

S. A. Mata, Jr.[1]

Counts of external indicators of attacks by the mountain pine beetle, Dendroctonus ponderosae Hopkins, throughout the infested length of five sampled ponderosa pines, were 1.5 percent greater than actual attacks.

Keywords: *Dendroctonus ponderosae, Pinus ponderosa.*

Bark beetle studies often require information about individual attacks on infested trees. It is useful to be able to identify attacks soon after they are made, using pitch tubes, frass exudations, and entrance holes as indicators. Many investigators have done this. Miller and Keen (1960) report using paper tags in marking attacks of Dendroctonus brevicomis Hopkins, and McCambridge (1967) marked individual attacks of D. ponderosae Hopkins with nails. Some attacks may not be readily seen, however, even with careful inspection.

To test the relationship between actual attacks and those indicated by these external signs, I marked attack points of D. ponderosae on Pinus ponderosa Lawson in the summer of 1971, and subsequently debarked the infested trees and counted egg galleries.

Methods

Two sites were selected in July 1971 on the Roosevelt National Forest, about 35 miles northwest of Fort Collins, Colorado. One artificially infested bolt was set out at each site to attract beetles. The first three trees attacked at one site and the first two at the other site were selected for study.

A thin band of aluminum paint was sprayed around the circumference of each tree at 1-foot intervals up to a 4-inch diameter to facilitate recording attacks. Individual beetle attacks as indicated by pitch tubes, frass, or entrance holes were marked on August 9-13, 17-20, 23, 26, 30 and September 7. Pins were inserted below each presumed attack location.

All trees were felled, bucked into 5-foot sections, and taken to the laboratory when the attack period was over. In the laboratory, the sections were debarked and all beetle attacks were checked against the pin counts.

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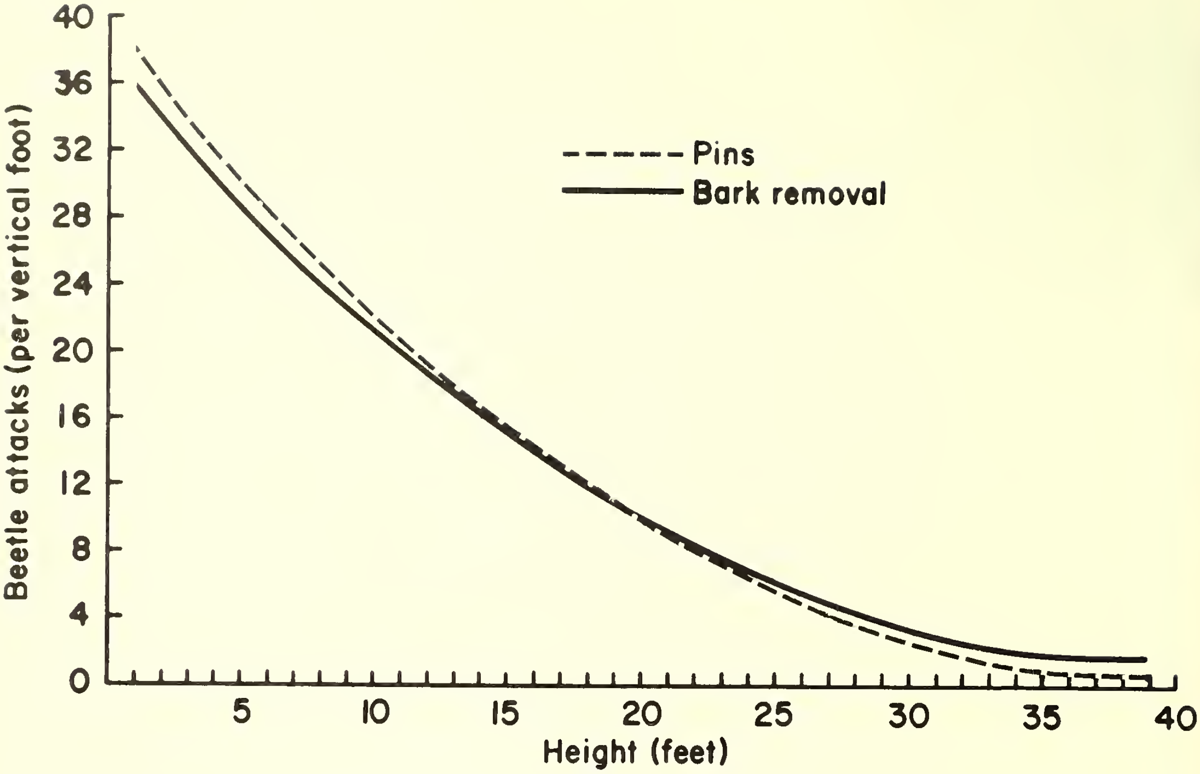

Figure 1.--Mountain pine beetle attacks as determined from bark removal (actual) and pin counts—mean of five trees.

Results

The number of attacks tallied by external indicators was strongly correlated (r = 0.996) with those found on the inner surface of the bark (fig. 1). Counts of external indicators differed from actual attacks by approximately ± 2.4 attacks for each foot interval throughout the height of the infested trees. There was a tendency to overcount attacks near the ground, and undercount those high in the tree.

There were 1.5 percent more external indicators than actual attacks (fig. 1). Actual attack counts did not always agree with external counts because: (1) Sap exuding from the entrance holes enveloped some pins, so that some attacks were tallied more than once, (2) bark scales concealed some attacks in the upper portions of the trees, (3) in the upper portions of the trees, sap exudation and/or frass was frequently absent so that many attacks beneath the bark scales were not readily found, (4) mountain pine beetle and *Ips* attacks were indistinguishable (during this study *Ips* beetles were not numerous, however), and (5) thick bark near the ground contributed to a higher pin count in this part of the tree because frass from a single attack would accumulate in more than one place.

With the exception that large *Ips* populations would seriously influence attack counts, most of the sampling errors are compensating. Therefore, counting external indicators offers an acceptably accurate, nondestructive method of measuring the intensity and distribution of mountain pine beetle attacks on standing trees.

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U S D A FOREST SERVICE
RESEARCH NOTE RM-223

OREST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Prediction of Air Temperature at a Remote Site from Official Weather Station Records

Ralph E. Campbell[1]

Air temperatures at the San Luis experimental watershed were predicted from temperatures at Albuquerque, New Mexico, on the basis of linear regressions between temperatures at the two locations calculated from a full year of continuous record at San Luis and official 3-hour records at Albuquerque. Hourly temperatures were predicted within ±6.3° to 7.8° F., depending on time of day. Predictions of daily mean temperatures at San Luis were within ±3.8° F. Monthly mean temperatures for a given time of day were predicted within ±3.6° to 5.5° F.

Keywords: Temperature forecasting, air temperature, weather patterns.

The air temperature at the local weather station is readily available. But to find the temperature at a site 60 miles away and 10 miles off the highway over rough country is much more difficult, particularly immediately after a thunderstorm in summer or a snowstorm in winter.

If the remote site is at similar elevation and is subject to weather patterns similar to those at the local weather station, temperature at the site may be estimated from local data (Thom 1968). A rancher, land manager, or research scientist may need this information.

How closely may he estimate the temperature at the remote site? The value of the estimate depends on the precision with which it is made. We continuously recorded the temperature for 1 year at the San Luis experimental watershed, which lies 60 air miles from Albuquerque, New Mexico. Using regression techniques, we determined the relationship of temperatures between Albuquerque and the experimental watershed.

Objective

The objective of this paper, then, is to show the precision with which temperature data may be projected from local records to predict the temperature at a remote site, in this instance San Luis watershed. From the calculations, we may predict the remote site temperatures for a point in time, a daily mean, or a monthly mean. We may set the limits, with 80 or 90 percent certainty, within which the true temperature lies.

Temperature Records

The San Luis watershed, elevation 6,540 feet, lies 60 air miles north-northwest of the Albuquerque airport, elevation 5,300 feet. The measurement site was a broad flood plain with a southerly slope of about 2 percent. Watershed rehabilitation and range production and utiliza-

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tion studies have been carried out at the San Luis site for several years. Air temperature was recorded continuously for 1 year at the experimental watershed with a type Vb mercury-filled temperature recorder. The stainless steel sensing bulb was suspended 1 foot above bare soil (fig. 1), shaded with a highly reflective sheet-metal cover about 6 inches above the bulb. Readings at 3-hour intervals were taken from the continuous-line charts at times corresponding with those reported by ESSA.[2] The march of temperatures at San Luis through a typical day in July and January is illustrated in figure 2.

Temperature at the Albuquerque airport was recorded from a sheltered hygrothermometer several hundred feet from any building and about 5 feet above ground level, over bare soil. The sensing unit was continuously ventilated by an aspirator. The site is a broad mesa with a westerly slope of about 1 percent.

Data Evaluation

Linear regressions of San Luis temperatures on Albuquerque airport temperatures were determined, and tolerance intervals for prediction of San Luis temperatures were calculated. Temperatures at 3-hour intervals, daily means, and monthly means at 3-hour intervals were evaluated. Serial correlation effects in the data were not calculated; considering the large number of observations, they were assumed to have no great effect on the results.

Regression Relations

Temperatures at the two locations may be related by the linear expression:

$$\hat{Y} = A + BX$$

where
Y = temperature at the remote site (San Luis),
X = temperature at the Albuquerque airport.

The correlation coefficients for Albuquerque versus San Luis temperatures ranged from 0.937 to 0.998 (table 1), indicating a very close relationship of temperatures between the two locations. Y intercept values (A) were all negative, indicating when Albuquerque temperatures were cold, San Luis temperatures were even colder.

Slopes of regression lines (B) exceeded 1 during daytime hours (0800 to 1700) and were less than 1 for nighttime (2000 to 0500). This relationship indicates that warming and cooling were both more intense at San Luis than at Albuquerque. That is, summer days tended to be warmer and nights cooler at San Luis than at Albuquerque.

Figure 1.--Temperature sensing bulb was suspend 1 foot above bare ground under highly reflect sheet metal cover. San Luis watershed III.

Figure 2.--Temperature record of a typical July January day at San Luis. Dots are predicted peratures Albuque tempera reco

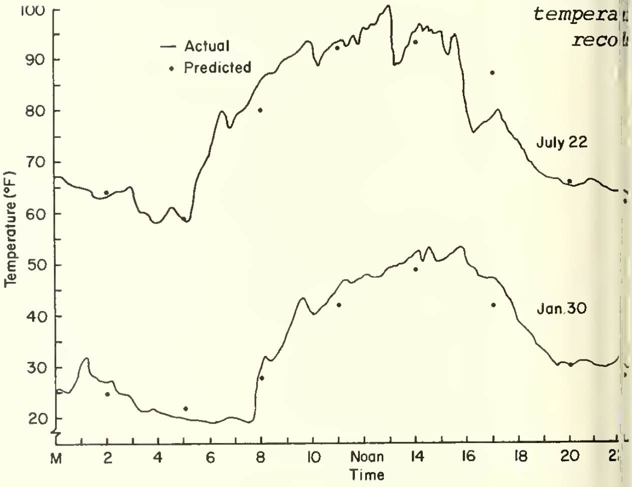

Table 1.--Linear regression components[1] and correlation coefficients between air temperatures at San Luis watershed and Albuquerque airport, November 1967 - October 1968

Hour	Daily			Monthly mean		
	A	B	r	A	B	r
0200	-3.31	0.892	0.944	-3.82	0.901	0.996
0500	-2.14	.869	.937	-2.36	.874	.994
0800	-3.51	1.082	.963	-4.51	1.103	.997
1100	-3.89	1.093	.965	-5.55	1.123	.998
1400	-7.62	1.103	.966	-10.83	1.157	.996
1700	-11.38	1.061	.966	-14.20	1.104	.996
2000	-5.84	.944	.966	-7.82	.978	.994
2300	-4.17	.903	.957	-4.66	.913	.994
Mean	-6.22	1.020	.988	-7.08	1.033	.997

[1] $\hat{Y}$=(A+BX) where $\hat{Y}$=temperature at San Luis, X=temperature at Albuquerque airport.

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[2] *Environmental Science Services Administration, Environmental Data Service. Local Climatological Data, Albuquerque, New Mexico, Sunport-Kirtland Air Force Base. 1967, 1968.*

Tolerance Intervals

The confidence coefficient used in this paper is 95 percent, with an 80 or 90 percent tolerance. Eighty (or ninety) percent of observed temperatures will fall within the tolerance interval centered on the predicted value with a 95 percent confidence. The 80 percent tolerance interval is, of course, narrower than the 90 percent interval. The tolerance interval was used rather than the usual confidence interval because the prediction equation will presumably be used repeatedly and estimates will be used concurrently throughout the year. The tolerance intervals used apply to the whole regression line (Lieberman and Miller 1962) and are considerably wider than the usual confidence intervals for a single future observation.

Tolerance intervals are narrowest at the mean and widen at higher and lower values (table 2).

The curves delineating the tolerance interval were hyperbolic with respect to the predictive equation regression line (fig. 3). However, for estimating tolerance limits using the values in table 2, a straight line configuration was assumed between the limits at $\bar{x}$ and those at $\bar{x} \pm 10°$; and between limits at $\bar{x} \pm 10°$ and those at $\bar{x} \pm 40°$. This assumption resulted in an error of less than 0.1°.

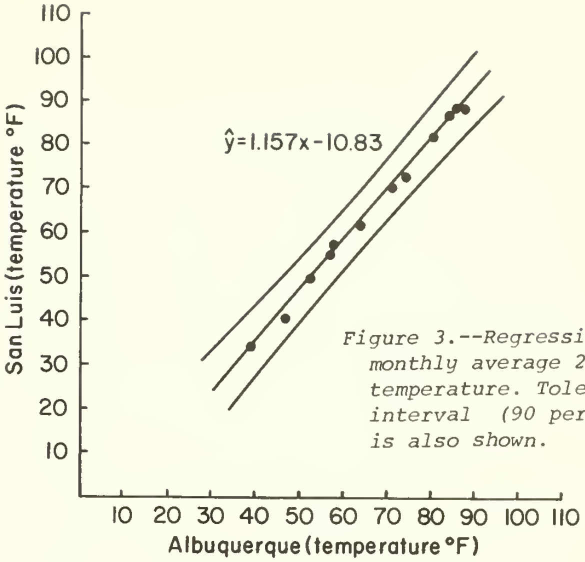

Figure 3.--Regression of monthly average 2 p.m. temperature. Tolerance interval (90 percent) is also shown.

Temperature Predictions

Daily

At a given hour of a day, the temperature at San Luis may be predicted within ±6.3° to

Table 2.--Tolerance intervals (°F.) of predicting daily and monthly 3-hour average temperatures at San Luis from temperatures at Albuquerque airport, November 1967-October 1968, 95 percent confidence

Hour	Mean daily temperatures ($\bar{x}$)		0.80 tolerance			0.90 tolerance		
	Albuquerque	San Luis	$\bar{x}$	$\bar{x} \pm 10^0$	$\bar{x} \pm 40^0$	$\bar{x}$	$\bar{x} \pm 10^0$	$\bar{x} \pm 40^0$
			- - - DAILY TEMPERATURES - - -					
0200	48.0	39.5	±6.9	±7.0	±8.2	±8.7	±8.8	±9.9
0500	45.2	37.1	6.8	6.9	8.1	8.6	8.7	9.9
0800	49.7	50.3	7.6	7.8	8.8	9.6	9.8	10.8
1100	60.1	61.8	7.7	7.8	8.8	9.7	9.8	10.8
1400	66.3	65.5	7.8	7.9	8.9	9.8	9.9	11.0
1700	65.3	57.9	7.5	7.6	8.6	9.5	9.6	10.6
2000	56.6	47.6	6.3	6.4	7.2	7.9	8.0	8.9
2300	51.8	42.6	6.3	6.4	7.4	7.9	8.0	9.0
Mean	55.5	50.4	3.8	3.9	4.4	4.8	4.9	5.4
			- - - MONTHLY TEMPERATURES - - -					
0200	48.0	39.4	±3.7	±4.0	±6.2	±4.5	±4.8	±6.9
0500	45.3	37.2	4.3	4.6	7.2	5.2	5.5	8.1
0800	49.7	50.3	5.0	5.2	7.5	6.0	6.2	8.6
1100	59.9	61.7	3.6	3.8	5.5	4.4	4.6	6.3
1400	66.3	65.9	5.5	6.9	8.5	6.6	7.0	9.6
1700	65.3	57.9	5.1	5.4	7.8	6.1	6.4	8.8
2000	56.7	47.6	5.5	6.9	8.6	6.6	7.0	9.7
2300	51.8	42.6	4.7	5.0	7.6	5.7	6.0	8.5
Mean	55.4	50.3						

±8.9°F., with 80 percent tolerance, depending on time of day and temperature. For example, assume the Albuquerque temperature at 2 p.m. (1400 hr.) is 75°F. Referring to table 1 for the equation values we have $Y = 1.103 \times 75 - 7.62 = 75.1°$. From table 2, the tolerance interval corresponding to the daily 1400 hr. temperature about 10° from the mean is ±7.9°. Thus the temperature at San Luis is predicted to be (with 80 percent tolerance) between 67°F. and 83°F., or 75.1°F. ± 7.9°. The prediction is somewhat closer during night hours. For example, if the Albuquerque temperature at 11 p.m. (2300 hr.) were 40°F., the San Luis temperature would be predicted (based on the above formula and tables 1 and 2) to be between 25.6°F. and 38.4°F., or 32.0°F. ± 6.4°, with 80 percent tolerance.

The daily mean temperature can be predicted considerably more closely: ±3.8° to ±4.4°. For example, if the Albuquerque mean temperature for the day were 55°F., the San Luis temperature for the day would probably be between 46°F. and 54°F., or 50°F. ± 4°. Here the mean daily values from table 1 are used in the formula.

Monthly

If the July, 11 a.m. average temperature in Albuquerque were 84°F. (24° greater than the mean), the 80 percent tolerance interval (table 2) would be interpolated as ±4.6°. Referring to the monthly values in table 1, the San Luis temperature then would be predicted to be $Y = 1.123 \times 84 - 5.55 = 88.8° \pm 4.6$, with an 80 percent tolerance.

The monthly mean prediction for a given hour in the day (table 2) carries a confidence interval closely comparable to the daily mean confidence interval. The confidence intervals associated with the monthly mean at 0200 and 1100 hr. are about the same as for the daily mean. The intervals for other hours are slightly wider.

Discussion

The daily spread of temperatures at the San Luis watershed was generally greater than at Albuquerque. This difference can be partially explained on the basis of sensor position; the unit at Albuquerque was 5 feet above the ground whereas the unit at San Luis was only 1 foot above the ground. Diurnal temperature variations decrease with distance above the ground. Air temperature decreases with height during the day, and the gradient generally inverts at night (Geiger 1965, p. 83). Thornthwaite (1948-53) and Sinclair (1922) showed that air layers near the ground become isothermal almost simultaneously at all levels shortly after sunrise and again at about 1600 and 1700 hr.

The San Luis temperature did not equal or exceed Albuquerque until after 0800 hr. during most months, and except during July and August dropped below Albuquerque temperature before 1500 hr. The evening and nighttime temperatures were often as much as 10° cooler at San Luis than at Albuquerque. Although the influence of height of sensor was evident in the data, the temperature patterns did not follow a simple height difference relationship, but were influenced by other local factors.

Variable afternoon cloudiness, characteristic of both Albuquerque and San Luis, markedly affects air temperature. Because of this cloudiness, afternoon temperatures at San Luis cannot be predicted precisely during the summer monsoon season. On the other hand, storm patterns and frequency at San Luis are quite similar to those at Albuquerque during the fall, winter, and spring. The predictive equation could be strengthened by using more than 1 year's data, or by averaging several stations.

The equation components developed precisely fit the temperature relations between the two sites, as illustrated by the extremely high correlation coefficients. The precision and limits of predictions are clearly defined. Thus, within the limitations to the approach presented here, a complete year of temperature data from a remote site are sufficient for reasonably reliable prediction of temperature at that site.

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U S D A FOREST SERVIC
RESEARCH NOTE RM-224

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Simulated Sonic Boom as an Avalanche Trigger

M. Martinelli, Jr.[1]

A linear array of detonating cord was used to simulate a sonic boom. The boom from such charges was directed toward the fracture zone of a small avalanche path where the snow was unstable, as indicated by natural avalanches in the area. On three of four tests, avalanches were released by a boom of 12 pounds per square foot (60 kg f/m^2) overpressure after withstanding lesser booms. One of the avalanches had a fracture face 8 feet 11 inches (272 cm) deep.

Keywords: Avalanche, sonic boom.

It appears obvious that snow can become unstable enough to be released by a sonic boom, since natural avalanches often occur with no obvious trigger. What is not known is the degree of instability at which sonic booms become important avalanche triggers. The consequences of widespread avalanche activity from frequent supersonic flights could be serious in areas of concentrated winter sports activity, at mining or hydroelectric sites, or along major mountain highways. As logical as the above arguments may be, there are still few well-documented cases of avalanches released by sonic booms (Vivona 1970).

Several attempts have been made in the western United States to release avalanches by supersonic overflights of military aircraft. So far, the results have been inconclusive. In one case,[2] fighter planes were maneuvered to concentrate and direct the boom at specific targets. Although a few avalanches were released, no data were taken on the overpressures, estimated at 3 to 4 pounds per square foot (p.s.f.), or the snow conditions. In another case (Lillard et al. 1965), logistics and communication problems delayed the tests so long the snow could not be released by the booms nor by artillery fire.

In this study, conventional explosives were used to simulate the shape, duration, and magnitude of the pressure-time trace of a sonic boom. Following the techniques of Hawkins and Hicks (1966), several strands of 50-grain detonating cord (fig. 1) were arranged to give a 100-millisecond N-wave. The magnitude of the overpressure was measured as a function of the distance from the end of the charge, and a calibration curve was prepared (fig. 2)(Mellor and Smith 1967).

Booms were simulated on two small avalanche paths near Berthoud Pass, Colorado. Although these paths occasionally avalanche naturally, and have been released numerous times in the past years by explosives tossed on the snow, they are considered two or three times more stable than several others in the vicinity.

During a test run, the 80-foot (24.4-m) long charge was suspended beneath a cable rigged above the long axis of the slide path. A system of pulleys allowed the end of the charge to be pointed toward the target area, and to be positioned properly for the desired overpressure (fig. 3). The charge was detonated by an ignition cap.

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[2] *Oral communication with Max E. Edgar, U.S. National Park Service, during Interagency Avalanche Conf., Santa Fe, N. Mex., April 1960.*

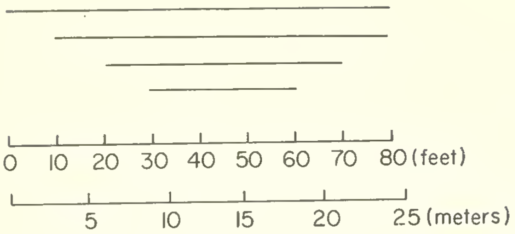

Figure 1.—Arroy of four stronds of 50-grain primocord os used to simulate 100-millisecond N-wove in this study (1 foot = 0.305 meter).

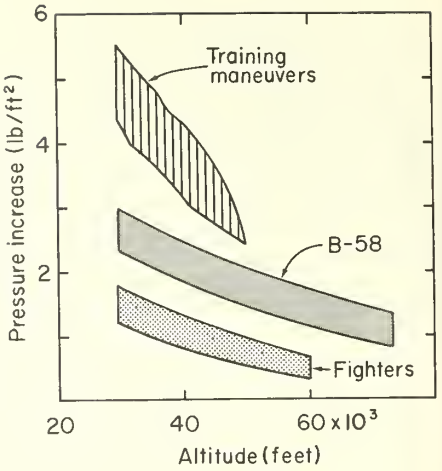

Figure 4.—Sonic boom exposure levels for routine militory flight operations (after Crow 1966).

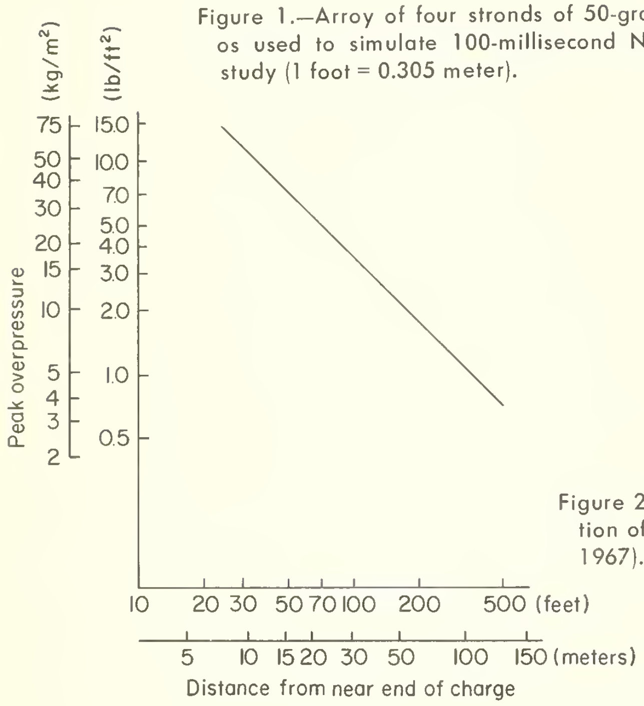

Figure 2.—Distance-overpressure colibration for simulation of 100-millisecond sonic boom (Mellor ond Smith 1967). (1 lb/ft^2 = 4.88 kg/m^2 or 0.488 g/cm^2)

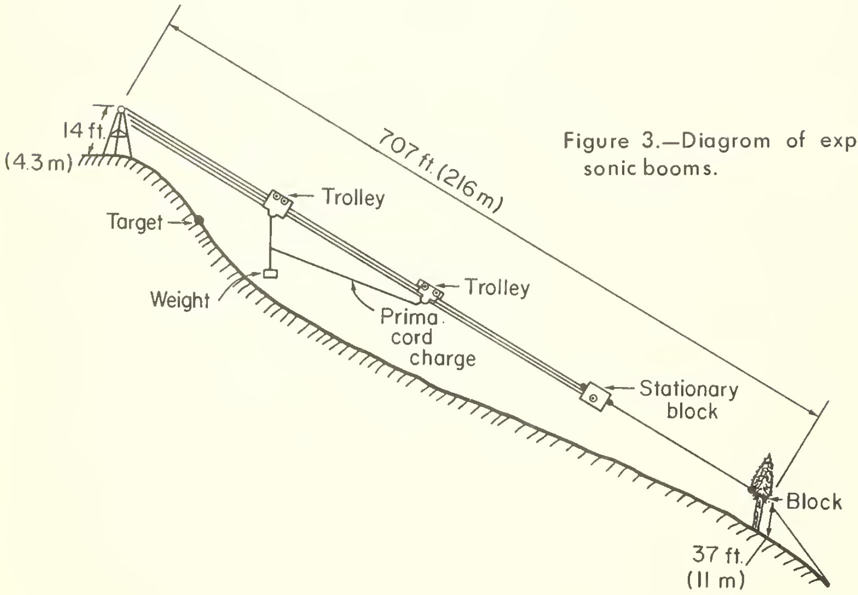

Figure 3.—Diagrom of experimental setup to simulate sonic booms.

When avalanche hazard was considered high, the more unstable of the two slopes was subjected to sonic booms of 3, 6, and 12 p.s.f. (15, 30, and 60 kgf/m^2) overpressure. These correspond roughly to normal, twice normal, and four times normal for level supersonic flight (fig. 4) (Carlson and McLean 1966). If no avalanche occurred, a 6- to 9-pound charge of HDP-1[3] was tossed into the target area to test snow stability in the same manner used in previous years when the area was used for skiing. At the end of each test, snow density, ram hardness, and snow crystal type were determined.

Three tests were run during the winter of 1969-70 and one the following winter. The simulated booms on February 5, 1970 produced a few cracks in the snow, but no avalanches. A 3-pound (1.36 kg) charge of HDP detonated in the target area, however, did release a 5-inch (13-cm) soft slab over about 20 percent of the area. This test was run early in a storm period that produced both hard and soft slab avalanches, most of which were small in size and the result of explosive control action (table 1). The 9 inches (23 cm) of fresh snow reported for February 4 contained 0.6 inch (15 mm) of water and fell with moderate winds and temperatures that had warmed 8° to 9° F. from the previous 2 days (table 2). From the snow profiles (fig. 5A), it appears that there were about 10 inches (25 cm) of new snow on top of a tough layer that was probably the prestorm surface layer.

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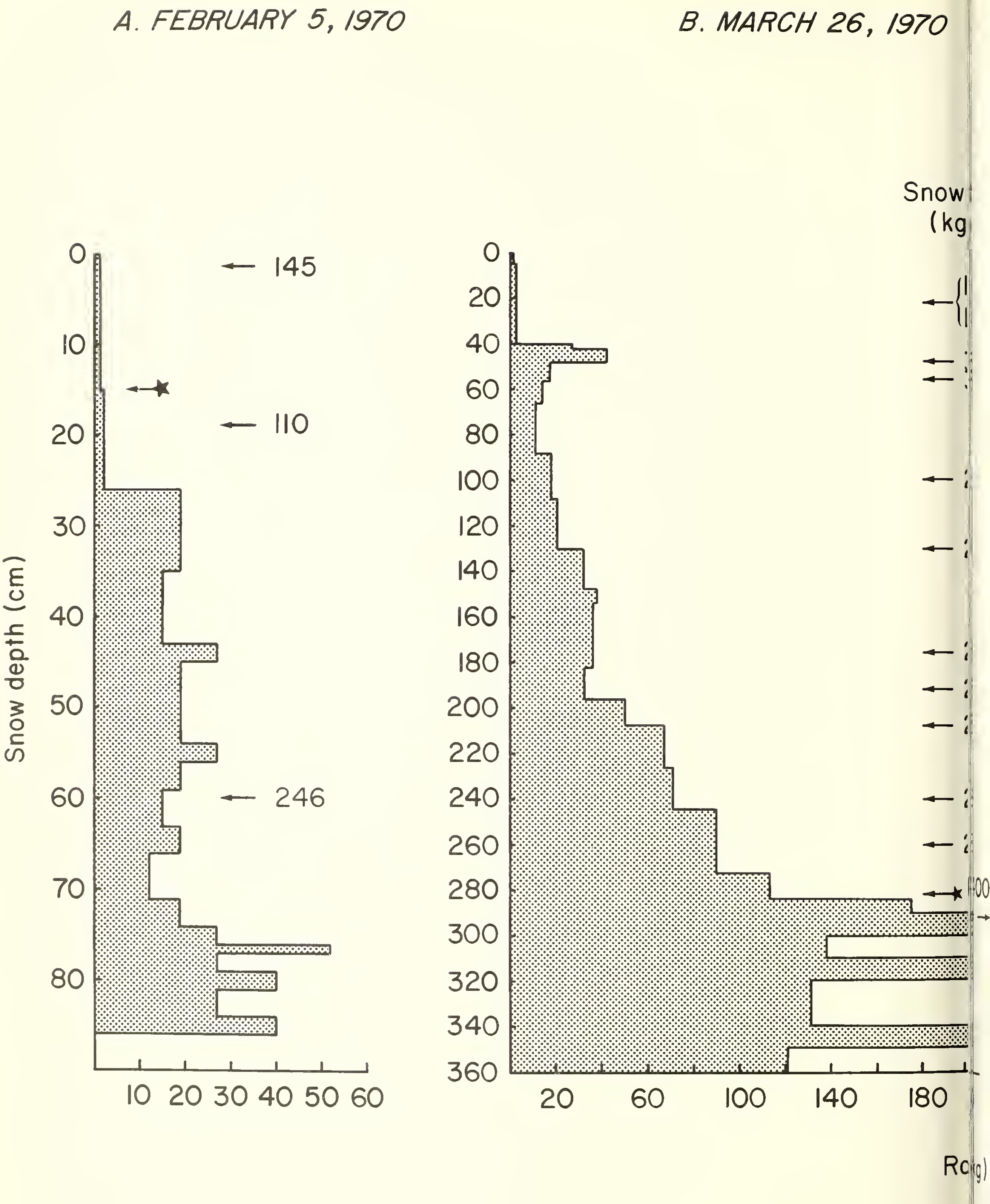
[3] *Dupont HDP-1 has a detonation rate of 24,000 feet per second, compared to 60 percent gelatin which has a rate of 16,000 feet per second. The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.*

Table 1.--Summary of avalanches within 12-mile (20 km) radius of the test site (test day is underlined; avalanches released by the booms are not listed)

Date	Type of avalanche			Trigger		Rating system for size					Total avalanches
	Hard slab	Soft slab	Loose	Natural	Explosive	Sluffs (1)	Small (2)	Medium (3)	Large (4)	Major (5)	
	Number										
February 1970											
2,3											0
4		1			1	1					1
5	1	4		2	3	1	1	2	1		5
6	2				2		1	1			2
7	2				2	1	1				2
Total	5	5	0	2	8	3	3	3	1		10
March 1970											
23		1		1			1				1
24	1	1			2			1	1		2
25	4	1		3	2		3		2		5
26	2				2		1	1			2
27	1				1		1				1
Total	8	3	0	4	7	0	6	2	3		11
April 1970											
18		5		3	2	1	3	1			5
19		2			2	1	1				2
20		3	1	2	2		1	2	1		4
21		1		1				1			1
22											0
Total	0	11	1	6	6	2	5	4	1		12
February 1971											
6	4				4		3	1			4
7											0
8	4			4			2	2			4
9											0
10											0
Total	8	0	0	4	4	0	5	3	0		8


A. FEBRUARY 5, 1970
B. MARCH 26, 1970
Snow depth (cm)
0
10
20
30
40
50
60
70
80
10 20 30 40 50 60
145
110
246
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
20 60 100 140 180
Snow
(kg
Ro
g)

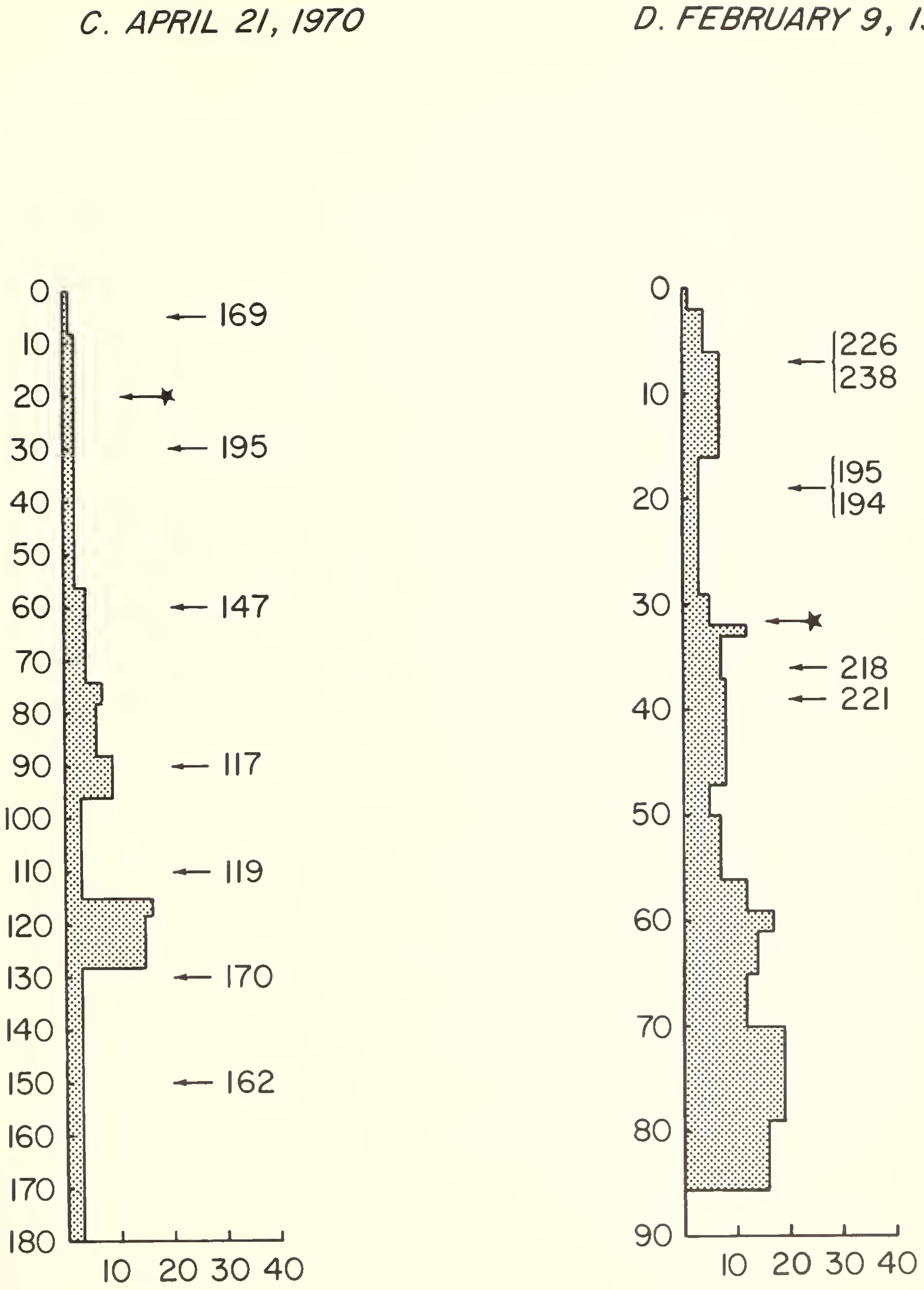


Figure 5.—Rammsonde profiles of the snow cover on test days. Notice the change in scale for part B.

Table 2.--Weather 3 days prior to each sonic boom test (date of the test is underlined)

Date	Precipitation		Temperature		Wind		
	New snow	Water equivalent	Maximum	Minimum	Direction	24-hour average	Gust
	- - Inches - -		- - °F - -			m.p.h.	
February 1970							
2	2.0	0.17	10	-1	NW	21	54
3	1.5	.09	7	-1	NW-WNW	22	52
4	9.0	.60	19	6	WSW-SW	17	58
5	4.0	.22	19	4	WSW-W	15	46
March 1970							
22	4.0	.28					
23	.5	.04	23	2	WNW	20	55
24	--	--	31	12	WNW	19	80
25	11.5	.89	34	1	VAR-NW	21	50
26	(1)	(1)	11	-6	NW-VAR-NW	12	34
April 1970							
18	6.0	.45	35	15	SW-NW	16	40
19	2.5	.14	22	9	NW-WSW-NW	12	35
20	9.5	.79	22	3	NNW-SW	18	45
21	1.0	.06	18	4	SW-VAR	16	41
February 1971							
6	3.5	.27	2	-9	WNW	17	52
7	1.0	.07	2	-18	NW	22	50
8	2.0	.19	5	-16	NW	23	42
9	1.0	.07	11	-3	NW	16	40

[1] Trace.

The hand-placed explosive charge released just the fresh snow with a density of 145 kg m^{-3} and a ram hardness of 1 kg or less. This snow slid on older snow that was a little tougher (ram no. 2 kg) than the new snow, in spite of its slightly lower density (110 kg m^{-3}).

On March 26, 1970, a major hard-slab avalanche was released by a 12-p.s.f. boom after the snow had withstood a 6-p.s.f. boom. This avalanche covered the entire test area (250 by 350 feet, or 75 by 110 m), had a fracture face 8 feet 11 inches (272 cm) deep, and a few debris blocks that measured 10 by 8 by 6 feet (3 by 2.5 by 2 m). The test was run toward the end of a period of predominantly hard slab activity (table 1). On March 25, 11.5 inches (29 cm) of new snow with 0.89 inch (23 mm) of water fell on the test site, accompanied by high temperatures and winds that gusted to 50 m.p.h. (22 m/sec). On the test day, precipitation dropped to a trace, winds slackened but continued to gust to 34 m.p.h. (15 m/sec), and temperature dropped sharply (table 2). The snow profile at the test site (fig. 5B) showed 16 inches (40 cm) of new, soft snow on top of about 20 inches (50 cm) of tougher snow. The high density of this young snow 40 to 50 cm below the surface is a good indication it was initial hard slab (Martinelli 1971), most likely deposited by the high wind of March 24 and 25. The fracture produced by the boom penetrated the new snow and well into the older snow before encountering a very tough layer. The avalanche ran on this hard, tough layer.

On April 21, the 12-p.s.f. boom released an 8-inch (20-cm) soft slab avalanche that ran about 100 feet (30 m) after 3- and 6-p.s.f. booms produced nothing but small surface cracks. Nine- and six-pound (4.1- and 2.7-kg) charges of HDP, detonated in the area for safety's sake, gave no additional fractures or avalanches. This test was made at the end of a moderate cycle of soft slab avalanche activity (table 1). The release was in fresh snow probably deposited the day before the test, when 9.5 inches (24 cm) of new snow with a water equivalent of 0.8 inch (20 mm) fell with moderate winds and warm temperatures (table 2).

The test on February 9, 1971 gave a small slab avalanche (130 ft wide by 150 ft long by 1 ft deep) and some surface cracks in response to a 12-p.s.f. boom. The 3- and 6-p.s.f. booms were not made because of mechanical problems caused by gusty winds. For the 3 days prior to the test, temperatures were low ($\leq 5°$ F.), precipitation less than 0.27 inch (7 mm) of water/day, and winds averaged 16 to 22 m.p.h. (7 to 10 m/sec) with gusts to 52 m.p.h. (23 m/sec). Four hard slab avalanches were released by explosives on February 6, and four more ran naturally during the night of February 8 on avalanche paths near the test site. Snow released by the boom was mostly wind deposited, with densities between 195 and 240 kg m^{-3} and ram hardness of 3 to 6 kg. This rather tough soft slab ran on a layer that was only slightly harder than the avalanching snow.

All avalanches released by simulated sonic booms required a threefold to fourfold amplification of the overpressure expected from normal supersonic flights. How often and under what circumstances terrain and atmospheric conditions in the mountains would give this amplification is not known (Roberts et al. 1967, Cook and Goforth 1967). Modeling experiments have shown, however, that certain terrain features can be expected to amplify peak overpressure 2 to 4 times, and that amplifications of 8 to 12 times normal are possible (Bauer and Bagley 1970). The simulated booms released avalanches only during periods when one-third or more of the avalanche activity in the local area was the result of natural releases.

In summary, this study suggests that, during periods of frequent natural avalanches, threefold to fourfold amplification of a normal sonic boom can be expected to release additional avalanches, some of which could be quite large.

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U S D A FOREST SERVIC
RESEARCH NOTE RM-225

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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

The Rocky Mountain Millivolt Integrator for Use with Solar Radiation Sensors

J. R. Thompson and A. D. Ozment[1]

Electronic integration of a radiometer's millivolt signal is a practical and accurate means of obtaining hourly, daily, weekly, or long-term radiation values. Our integrator consists of four printed circuit boards, a synchronous bi-directional stepper motor, and 5-decade counter. Each integrator is calibrated to match the millivolt output of the radiation sensor, so that the counter reads directly in langleys. The totalizing of a signal from a typical net radiometer with a 6.20mv/langley output) would be within ±1 percent over most of the positive signal range, but could be 5 percent too low at night when the sensor output is negative.

Keywords: Solar radiation, instrumentation, electronic equipment.

Electronic integration is a practical and accurate means of obtaining radiation values over any time period greater than about a minute. Most often we are interested in daily, monthly, or yearly values. Reducing radiation data from strip charts is time consuming and inaccurate.

The Rocky Mountain millivolt integrator, designed for either a solar pyranometer (fig. 1) or net radiometer, is calibrated to match the millivolt output of the sensor so that it reads directly in langelys.

There are several integrators or totalizers described in the literature. A list of references on the subject is given at the end of this Note. Tanner (1965) did an excellent job of describing the various types of integrators available at that time. Since 1965, advances in integrated circuits have allowed an increase in instrumental accuracy and a decrease in power requirements. The integrator described here is unique in that it employs a bi-directional stepping motor to drive a counter.

Figure 1.--Voltage integrator sums millivolt signal from pyranometer directly in langleys and displays it on a 5-decade counter. It can be read over any time period of interest from 5 minutes to several days.

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[1] *Meteorologist and Physicist, respectively, located at the Station's Forest Hydrology Laboratory at Tempe, in cooperation with Arizona State University; Station's central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.*

Integrators that employ the coulometer, Solion, or other types of electrolytics are probably the most economical, but they are also the least accurate, mainly because of readout difficulties. A major drawback to many of the integrators discussed in the literature is the large DC current drain, or the need for AC current.

The Rocky Mountain integrator combines accuracy, low cost, and low power requirements. The cost of the instrument we built was approximately $150. Current drain averaged slightly over 300 milliamps.

Construction and Principle of Operation

The Rocky Mountain millivolt integrator consists of four printed circuit boards (three when used with a pyranometer), a synchronous bi-directional stepper motor, and a 5-decade counter. A block diagram and an overall schematic of the integrator are given in figure 2. The four printed circuit boards are illustrated schematically in figures 3, 4, and 5, and photographically in figure 6.

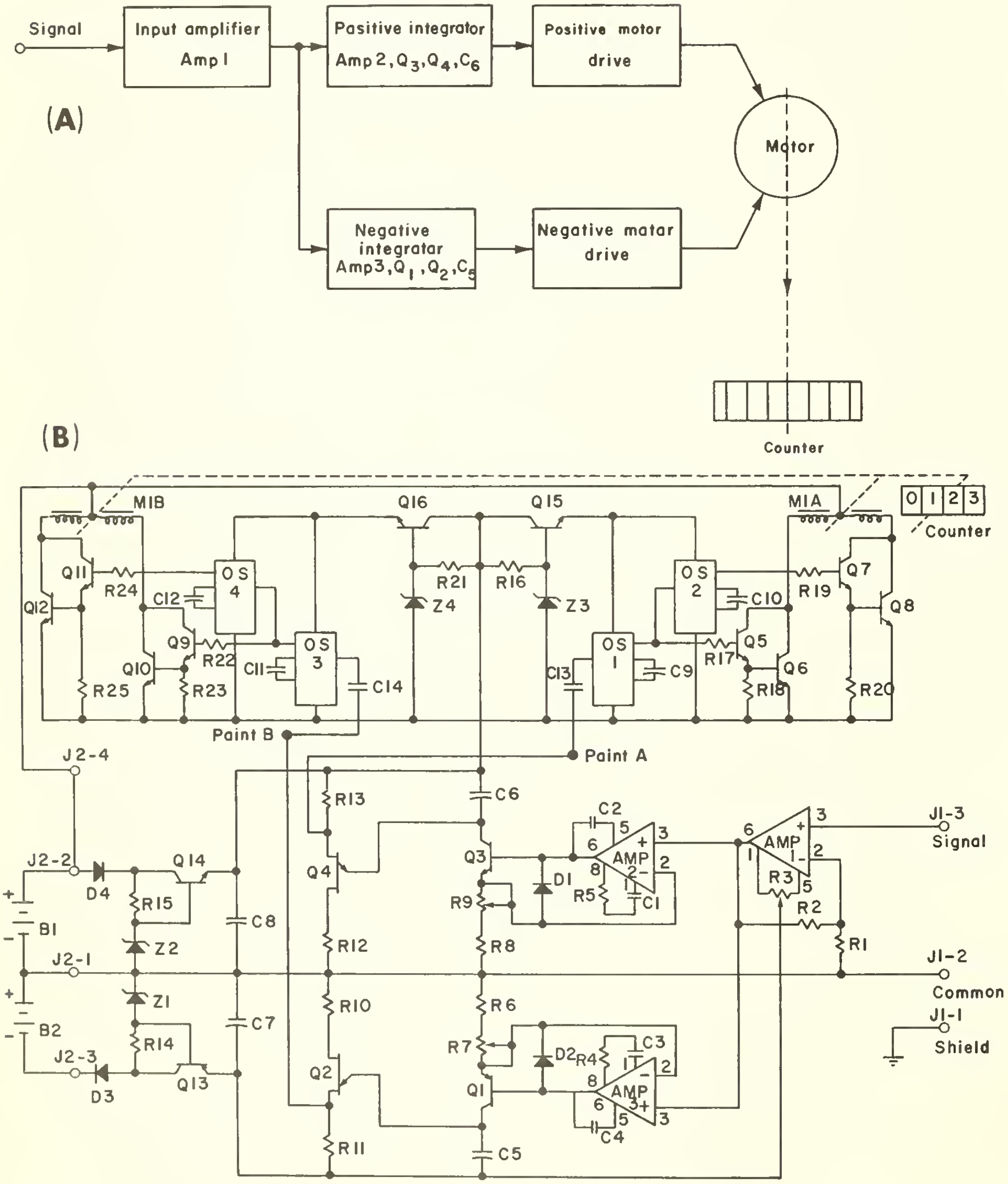


Figure 2.--Rocky Mountain millivolt integrator: A, block diagram; B, schematic diagram.

*Figure 3.--
Power supply board schematic for Rocky Mountain integrator.*

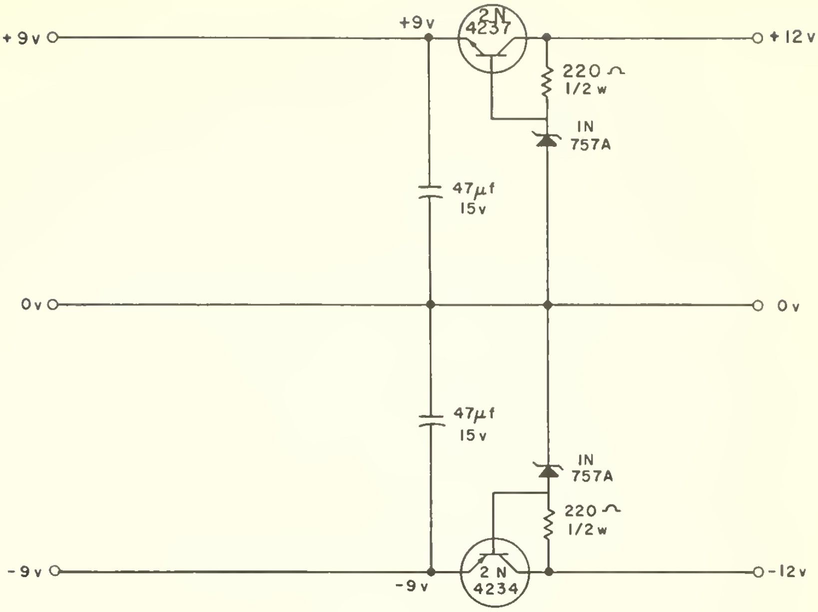


*Figure 4.--
Motor driver board schematic for Rocky Mountain integrator. Two required for net radiometer, one for solar pyranometer.*

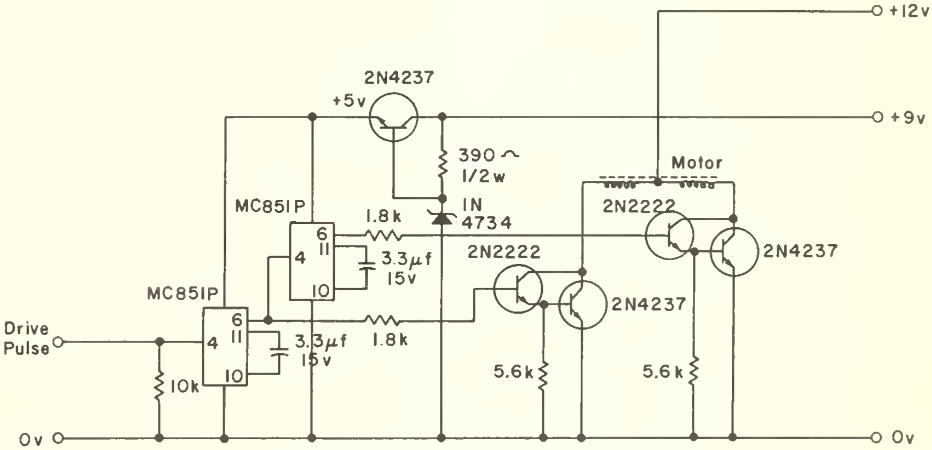
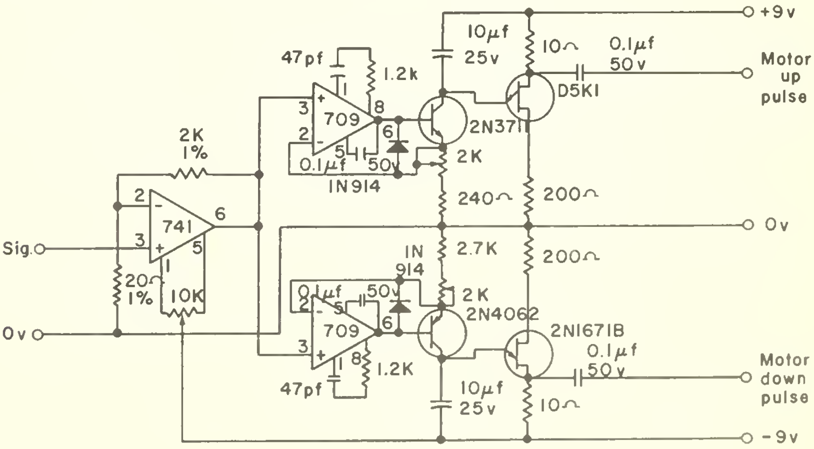


*Figure 5.--
Amplifier board schematic for the Rocky Mountain integrator.
NOTE:
+9v and -9v used to supply amplifier modules.*



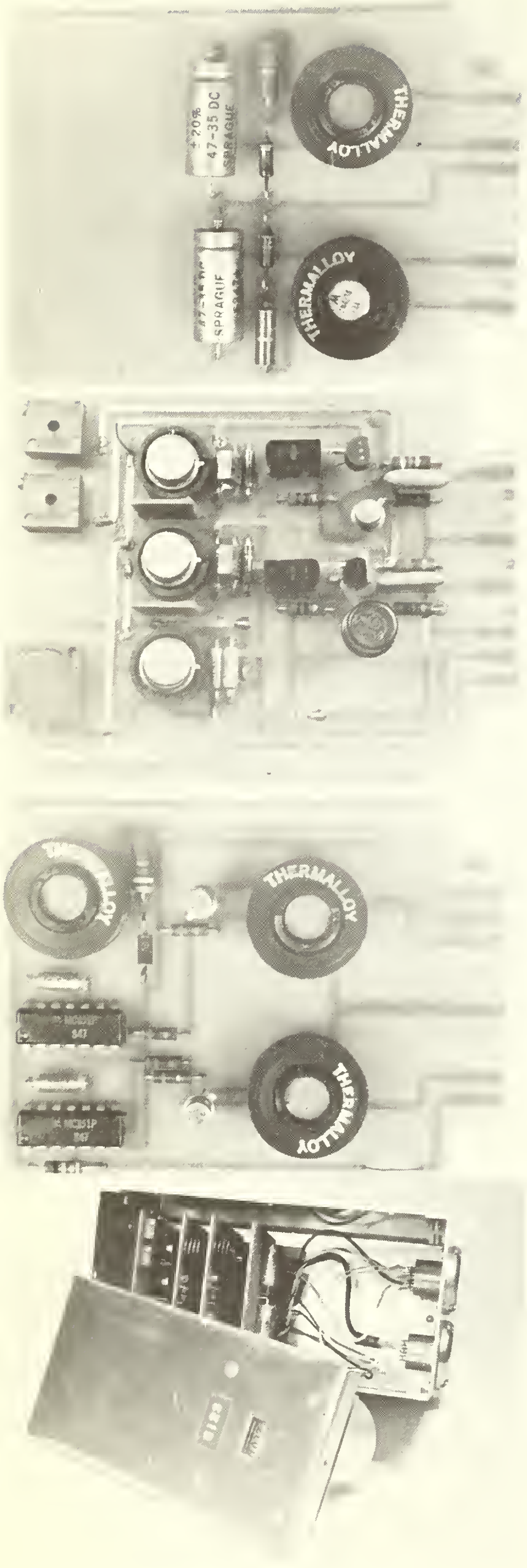


Figure 6.-- The printed circuit board layout used in the Rocky Mountain integrator:

A, power supply;

B, amplifier;

C, motor driver;

D, the completed unit.

The integrator is similar to several other integrators defined as "relaxation oscillators" by Tanner (1965). It is unique in that it uses a bi-directional stepping motor to drive a counter. The stepping motor is driven by pulses from two integrating circuits, one for positive and one for negative input signals. The two integrating circuits are calibrated separately, thus allowing the output of a net radiometer to be totalized.

In figure 2B, the input amplifier, Amp 1, is a low-drift integrated-circuit operational amplifier with internal frequency compensation. It is connected in the non-inverting mode which presents a high input impedance to the input signal. The gain is set at 1000 by the ratio R2/R1. R3 is a balance adjustment used to set the output of Amp 1, with zero signal, to compensate for offsets in Amp 1, Amp 2, and Amp 3.

The positive integrator is composed of Amp 2, Q3, and Q4. Amp 2 and Q3 charge C6 with a current equal to (1000 × Sig)/(R8 + R9). When the voltage across C6 reaches the peak point of the complementary unijunction, Q4, the unijunction conducts and discharges C6. A pulse is fed to the shaping and driving circuits consisting of monostable multivibrators, OS1 and OS2, and associated transistors. The negative integrator consists of Amp 3, Q1, and Q2, which drive OS3 and OS4 and their transistors.

Calibration

An accurate voltage divider was developed to insure proper calibration of the voltage integrator for a given radiometer. This allows long-term calibration checks with constant (±0.0025 percent) millivolt inputs within the range of the output level from a radiation sensor.

The bench setup used in calibrating the integrator is shown in figure 7. The voltage divider is used to simulate the output from the radiometer that will be used with a particular integrator. A precision millivolt potentiometer is necessary to adjust the output from the divider to the desired levels that will make the integrator read directly in langleys.

Because the integrator output is linear with respect to input, only one point of each polarity of input is necessary for calibration. This point was arbitrarily chosen to represent 1.0 langley.

When the input voltage is set at the level representing 1.0 langley, the time interval between pulses from the integrating circuits (Point A for positive input, Point B for negative, fig. 2B) is set with R9 and R7, respectively. The time interval should be 100 milliseconds at 1.0 langley and 400 milliseconds when checked at 0.25 langley. Using a frequency counter with period averaging, the period can be set to 1/2 percent on the high level with 2 percent accuracy on the low level.

Long-term precision of the integrator was tested by supplying a constant input voltage from the divider over a period of 5 days. The error in voltage integration was only -0.9 percent on the negative input side and ± 0.6 percent on the positive input side.

Calibration tests under temperature conditions ranging from 75° to 108°F are presented in figure 8. Because wet-cell batteries are required

Figure 7.--To accurately calibrate the voltage integrator for a given radiometer, an accurate voltage divider was developed by the Rocky Mountain Station. This allows long-term calibration checks with constant (± 0.0025 percent) milivolt inputs that simulate the output from a radiation sensor.

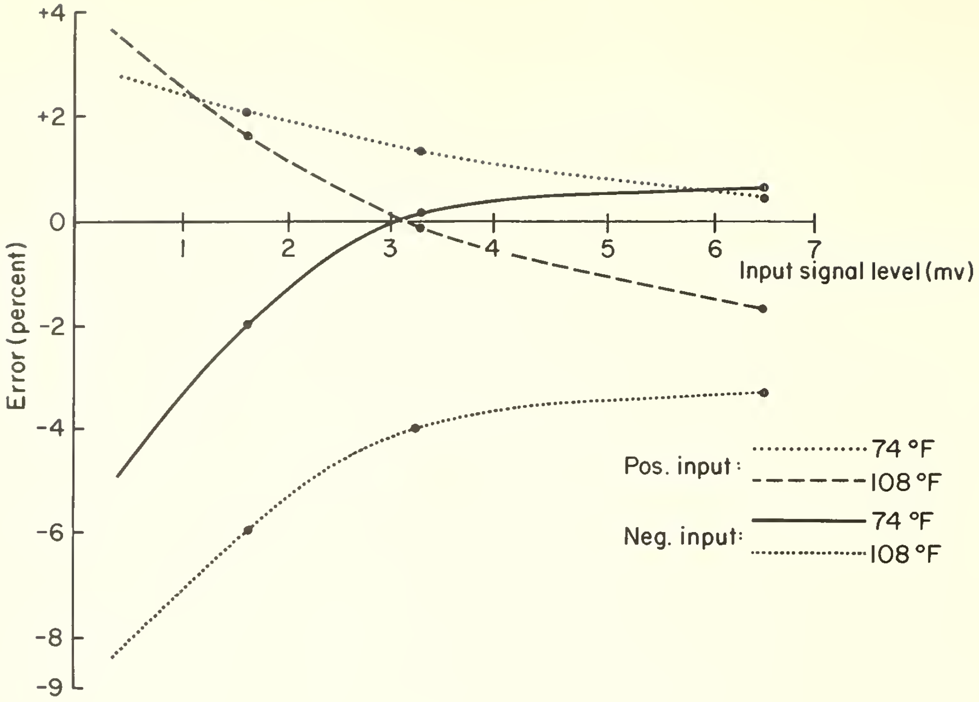


Figure 8.--Variations in the calibration of the RM millivolt integrator with temperature and signal level.

for a power source, a heated shelter is required when freezing temperatures are encountered. Maintaining a shelter environment of 75° to 100° F would minimize the integrator errors caused by temperature drift. Negative net radiation amounts to only 10 to 20 percent of the daily total, therefore a 5 to 6 percent nighttime integrator error is comparable to a 1 to 2 percent daytime error. If nighttime values are of interest by themselves, the shelter temperature becomes more critical in order to minimize the negative integrator error.

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Parts List[2]

B1	Battery, 12v lead-acid
B2	Battery, 12v lead-acid
C1	Capacitor 47pf
C2	Capacitor 0.1μf
C3	Capacitor 47pf
C4	Capacitor 0.1μf
C5	Capacitor 10μf, 15v
C6	Capacitor 10μf, 15v
C7	Capacitor 47μf, 15v
C8	Capacitor 47μf, 15v
C9	Capacitor 3.3μf, 15v
C10	Capacitor 3.3μf, 15v
C11	Capacitor 3.3μf, 15v
C12	Capacitor 3.3μf, 15v
C13	Capacitor 0.1μf
C14	Capacitor 0.1μf
D1	Diode 1N914
D2	Diode 1N914
D3	Diode 1N4005
D4	Diode 1N4005
J1	Jack 91-855 (Amphenol)(Mates 91-854)
J2	Jack 91-859 (Amphenol)(Mates 91-858)
M1	Stepping motor K-44135-P2; 50:1 gear reduction (A. W. Haydon)

Counter A1141 25-005 (Veeder-Root)

Edge connectors 251-20A-30 (Cinch-Jones)

Q1	Transistor 2N4062
Q2	Transistor 2N3711
Q3	Transistor 2N3711
Q4	Transistor D5K1 (G.E.)
Q5	Transistor 2N2222A
Q6	Transistor 2N4327
Q7	Transistor 2N2222A
Q8	Transistor 2N4237
Q9	Transistor 2N2222A
Q10	Transistor 2N4237
Q11	Transistor 2N2222A
Q12	Transistor 2N4237
Q13	Transistor 2N4234
Q14	Transistor 2N4237
Q15	Transistor 2N4237
Q16	Transistor 2N4237

Unless otherwise stated,
all resistors are ± 5%, 1/4W

R1	Resistor 20Ω, ± 1%, 1/4W
R2	Resistor 2KΩ, ± 1%, 1/4W
R3	Variable resistor 10K, Pot.; Bourns #3280P-1-103
R4	Resistor 1.2KΩ
R5	Resistor 1.2KΩ
R6	Resistor 2.7Ω (Selected for proper range of calibration adjustment)
R7	Variable resistor 2.7Ω, Pot.; Bourns #3280P-1-202
R8	Resistor 240Ω (Selected for proper range of calibration adjustment)
R9	Variable resistor 2KΩ, Pot.; Bourns #3280P-1-202
R10	Resistor 200Ω

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[2] *The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.*

R11	Resistor 10Ω
R12	Resistor 200Ω
R13	Resistor 10Ω
R14	Resistor 220Ω, ± 5%, 1/2W
R15	Resistor 220Ω, ± 5%, 1/2W
R16	Resistor 390Ω, ± 5%, 1/2W
R17	Resistor 1.8KΩ
R18	Resistor 5.6KΩ
R19	Resistor 1.8KΩ
R20	Resistor 5.6KΩ
R21	Resistor 390Ω, ± 5%, 1/2W
R22	Resistor 1.8KΩ
R23	Resistor 5.6KΩ
R24	Resistor 1.8KΩ
R25	Resistor 5.6KΩ
Z1	Zener diode 1N4739A
Z2	Zener diode 1N4739A
Z3	Zener diode 1N4734A
Z4	Zener diode 1N4734A
Amp 1	Operational amplifier U5B7741312 (Fairchild)
Amp 2	Operational amplifier U5B770931X (Fairchild)
Amp 3	Operational amplifier U5B770931X (Fairchild)
OS1	Monostable multivibrator MC851P (Motorola)
OS2	Monostable multivibrator MC851P (Motorola)
OS3	Monostable multivibrator MC851P (Motorola)
OS4	Monostable multivibrator MC851P (Motorola)

U S D A FOREST SERVIC
RESEARCH NOTE RM- 226

OREST SERVICE
.S. DEPARTMENT OF AGRICULTURE

KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

Effects of Wildfire on Elk and Deer Use of a Ponderosa Pine Forest

William H. Kruse[1]

After a wildfire, elk use shifted from an old seeded clearcut to a newly seeded burn for the first 2 years. The third year showed an equalizing trend of elk use between the two habitat conditions. The trend of decreasing deer use on thinned areas continued, but use increased substantially on the wildfire area.

Keywords: Forest fire effects, habitat (wildlife), deer, elk.

A lightning strike caused a wildfire in May 1967 which burned 350 acres of ponderosa pine[2] forest on the Wild Bill Range Study area north of Flagstaff, Arizona (fig. 1). Since prefire use data on thinned, clearcut, and seeded clearcut areas were available (Pearson 1968), the opportunity was provided to compare elk and deer response to new conditions created by the wildfire. The elongated burned area was sufficiently narrow to be considered a "forest opening," known to be preferred by elk and deer (Reynolds 1966).

Study Area

The Wild Bill study was designed to evaluate the effect of ponderosa pine density on forage and beef production in north-central Arizona (Pearson and Jameson 1967). The study area, located 13 miles northwest of Flagstaff on the Coconino National Forest, covers approximately 1,100 acres. The elevation varies from 7,400 feet to over 7,800 feet. Average annual precipitation is approximately 23 inches.

The original treatments, which began in 1962, established seven Range Units—two clearcut pastures, one of which was seeded; four pastures thinned to basal area levels ranging from 20 to 80 square feet; and a native pasture as a control. Range Unit 8, a second control, was established in 1967 after the fire.

The major native grasses on the area include Arizona fescue, mountain muhly, bottlebrush squirreltail, and a sedge. Some of the more dominant forbs include fleabane, thistle, western yarrow, and senecio. Fendler ceanothus is the only browse species on the area. At the onset of the study in 1962, one of the clearcut units (Range Unit 1) was seeded with crested wheatgrass, intermediate wheatgrass, and yellow sweetclover. Vegetation in all other units was left native until after the fire in May 1967.

The hot crown fire, which decimated the standing forest and burned herbaceous cover and litter to mineral soil, was confined primarily to the Holding Pasture, Range Unit 7, and the south edge of Range Unit 3. Because of earlier thinning treatments in Range Unit 3, the lack of fuel restricted the crown fire to the edge of that Unit. A 6-pound-per-acre seed mix, consisting primarily of orchardgrass with lesser amounts of several wheatgrasses and yellow sweetclover, was broadcast by helicopter over

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[1] *Range Research Technician, located at the Station's Forestry Sciences Laboratory at Flagstaff in cooperation with Northern Arizona University; Station's central headquarters is maintained at Fort Collins in cooperation with Colorado State University.*

[2] *Common and botanical names of plants mentioned are listed at the end of the Note.*

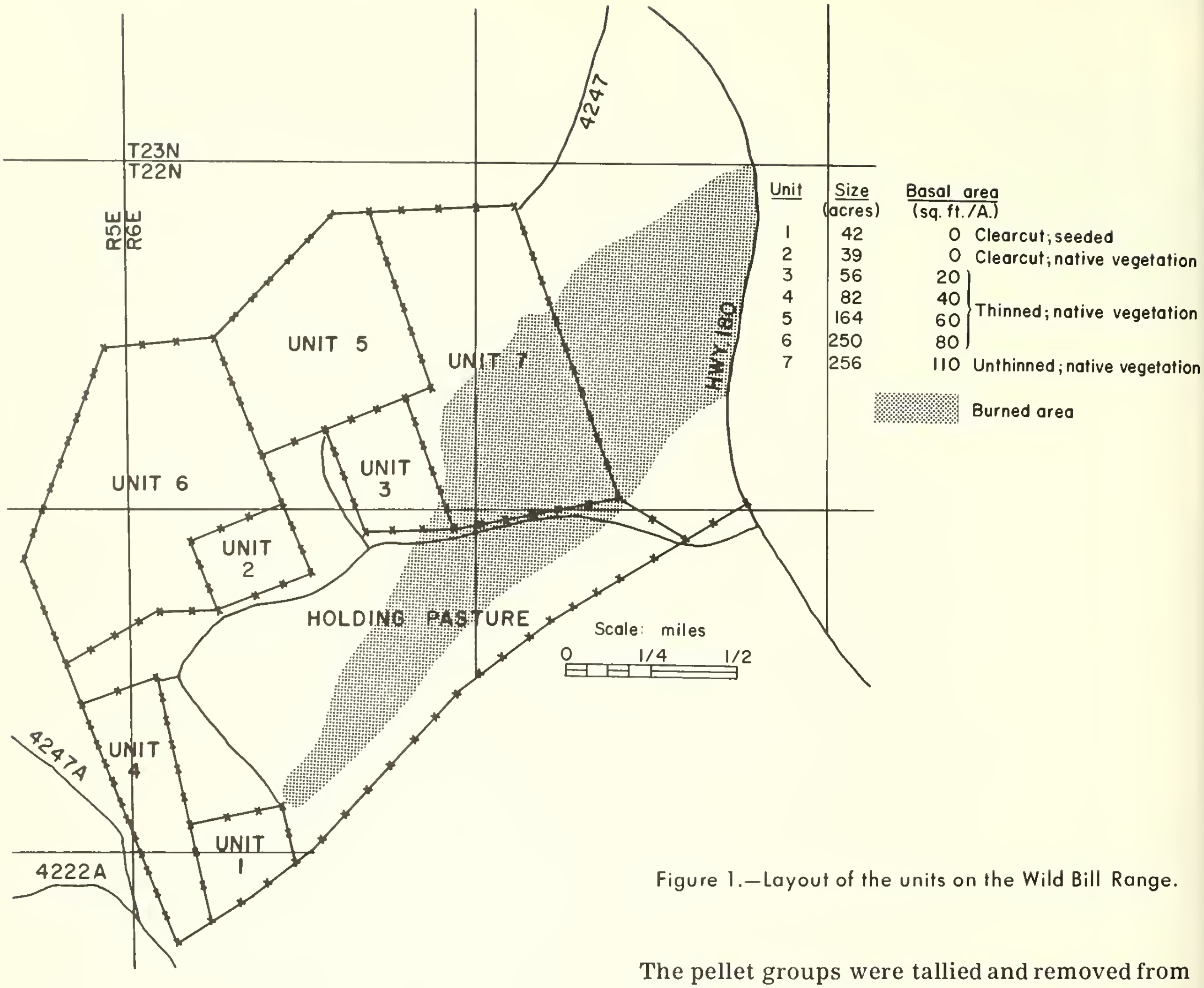

Figure 1.—Layout of the units on the Wild Bill Range.

the entire burned area in July 1967 just prior to the summer rains. Cattle grazing was deferred on the burned units for 2 years following the seeding.

Average forage production on the burned portion of Range Unit 7 for the 5 years prior to the fire and for 3 years following was:

	Prefire	**Postfire**
	(Pounds per acre)	
Grasses	45	395
Forbs	12	532
Shrubs	>1	56

Use Measurements

Elk and deer pellet groups were sampled on 15 clusters in each of the Range Units. Each cluster consisted of three circular 0.01-acre plots. The pellet groups were tallied and removed from the plots in November of each year. Forage production was also estimated each year. Since 1969, a weight-estimate method was used to make these determinations (Pechanec and Pickford 1937). Prior to 1969, a paired-plot procedure was used to determine utilization by cattle periodically during the grazing period. Yearly production figures were calculated from these data and residue figures.

Pellet groups were counted annually in 1968, 1969, and 1970. One hundred and thirteen 0.01-acre temporary plots (Neff 1968) were examined on four transects running the length of the burn in the Holding Pasture. The plots were spaced approximately 50 yards apart along the transects (fig. 1). Pellet groups dropped prior to the fire were burned. The count made in 1969 represented a 2-year accumulation, and the count in 1970 represented a 3-year accumulation. Annual pellet group increment was determined by subtracting previous counts from the current total accumulation.

Forage production and utilization were not measured in the Holding Pasture.

Results and Discussion

Elk Observations

During the prefire years following the original treatments, elk use was declining in most of the units except in seeded clearcut Unit 1, which showed the greatest amount of elk activity (table 1). After the 1967 fire, elk grazing on the seeded clearcut was reduced as use shifted to the burned area. The first and second years after the fire, pellet groups on the seeded clearcut showed a considerable reduction from preburn counts.

The pellet group densities in the burn reached peaks similar to those previously attained in the seeded clearcut. The third year (1970) showed a decrease in elk pellet counts on the burned areas, but an increase again in the seeded clearcut. A similar early peak of elk use on newly seeded areas was documented by pellet group counts taken on the Beaver Creek Pilot Watershed 11;[3] after the initial response, elk concentrations declined somewhat, but continued high use indicated a preference for seeded areas (Wallmo 1964).

Reinstated cattle grazing on the burned areas possibly influenced this decrease on Wild Bill. Similar observations were reported by researchers in Oregon (Skovlin, Edgerton, and Harris 1968) and in California on tule elk (McCullough 1969). During the 2 years that grazing was not permitted on the burn (1967 to 1968), elk were observed from time to time, as were fresh tracks and pellet droppings in the burn itself, and numerous rubbing trees in timbered areas along the edge of the burn. These indicators were not obvious during the summer in years prior to the fire, nor in the years succeeding the reinstatement of cattle.

Deer Observations

After the fire, deer pellet groups increased in the burned areas (table 1). As with the elk, sightings of deer became more numerous in 1968 and 1969 before cattle were allowed to return to the newly seeded areas. In 1970 after cattle grazing had been reinstated, deer were still seen in these areas, but not with the consistency of the previous 2 years.

Observations since the wildfire indicate an improved habitat for deer. This is consistent with other studies of prescribed and wildfire burning of deer habitats, especially where browse species increased (McCulloch 1969, Vogel and Beck 1970).

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[3] *Unpublished data, Rocky Mountain Forest and Range Experiment Station and Arizona Game and Fish Department.*

Table 1.--Yearly elk and deer pellet groups per acre, 1964-70

Range unit and treatment	Elk pellet groups							Deer pellet groups						
	1964	1965	1966	[1]1967	1968	1969	1970	1964	1965	1966	[1]1967	1968	1969	1970
	Number													
CLEARCUT:														
1 Seeded	27	64	13	51	2	4	22	16	7	7	2	0	2	4
2 Native	9	2	3	0	4	0	--	42	11	11	0	7	0	--
THINNED:														
3 20 Basal area	7	9	2	0	--	0	--	4	13	2	9	--	0	--
4 40 Basal area	13	4	2	0	0	0	--	124	31	2	2	0	0	--
5 60 Basal area	7	11	2	0	0	0	--	36	33	2	0	2	0	--
6 80 Basal area	4	4	4	0	0	0	--	33	0	0	2	4	0	--
UNTHINNED:														
7	0	0	0	0	37	52	11	18	4	0	0	11	26	67
8	--	--	--	0	2	0	0	--	--	--	0	2	0	0
HOLDING PASTURE	--	--	--	--	19	72	30	--	--	--	--	4	0	11

[1] The wildfire in 1967 severely affected portions of Unit 7 and the Holding Pasture. Postfire pellet group counts are reported only for the burned portion of these units. Unit 3 was only slightly affected.

Burned areas on Wild Bill showed a steady increase in numbers of pellet groups per acre in the 3 years following the fire, while no important increase in deer pellet groups was observed in any of the other range units.

Summary and Conclusions

Annual pellet count data on the Wild Bill Range indicate that forest openings, created by wildfire and followed by seeding, are just as attractive to elk as are open habitat conditions created by clearcut and seeding methods. Elk use on the burned areas was higher than on the thinned or clearcut areas for 2 years following the fire. Increased elk sightings during the summer and fall indicated a shift away from spring use patterns to season-long use on the newly seeded burn.

Elk use peaked and then fell off in the years following the original treatments. Use on the native (unseeded) clearcut area was lower than on the seeded areas, but showed more year-to-year stability than use on the thinned areas.

Prefire pellet group counts show a yearly decline in deer use on most of the treated areas. Deer use increased on the seeded wildfire opening, however.

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Common and Botanical Names of Plants Mentioned

Ceanothus, Fendler	*Ceanothus fendleri* Gray
Fescue, Arizona	*Festuca arizonica* Vasey
Fleabane	*Erigeron* sp.
Muhly, mountain	*Muhlenbergia montana* (Nutt.) Hitchc.
Orchardgrass	*Dactylis glomerata* L.
Pine, ponderosa	*Pinus ponderosa* Laws.
Sedge	*Carex geophila* Mackenz.
Senecio	*Senecio* sp.
Squirreltail, bottlebrush	*Sitanion hystrix* (Nutt.) J. G. Smith
Sweetclover, yellow	*Melilotus officinalis* (L.) Lam.
Thistle	*Cirsium* sp.
Wheatgrass, crested	*Agropyron cristatum* (L.) Gaertn.
Wheatgrass, intermediate	*Agropyron intermedium* (Host.) Beauv.
Yarrow, western	*Achillea lanulosa* Nutt.

Agriculture—CSU, Ft. Collins

1972

U S D A FOREST SERVIC
RESEARCH NOTE RM-227

OREST SERVICE
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KY MOUNTAIN FOREST AND RANGE EXPERIMENT STATIO

A Centrifugal Tensile Tester for Snow

R. A. Sommerfeld and F. Wolfe, Jr.[1]

A new centrifugal tensile tester has been designed for snow samples. The new design corrects many of the deficiencies of the older design.

Keywords: Snow avalanches, snow management, tensile strength, centrifugation.

The centrifugal tensile tester (Bader et al. 1951) has been used to test many snow specimens (Butkovitch 1956, Keeler 1969, Keeler and Weeks 1967, Martinelli 1971). Some inadequacies in the original design have become apparent with use. A new tester was therefore designed to overcome the following difficulties:

Variable stress rate.--With the older tester, the operator increased the spin rate until the sample failed. Thus the spin rate varied among samples, and it was impossible to determine its rate of increase precisely. Therefore, a photoelectric circuit was designed which turns off the drive motor when the sample fails. With the automatic turnoff, full power can be applied to the motor so that it accelerates rapidly, under its own inertia, to the point of sample failure. A recording of the tachometer output provides an accurate and permanent record of the acceleration of the spin rate.

Inaccuracy of spin rate determination.--The output of the older tester was observed visually on a tachometer dial. The operator attempted to observe the dial reading at the time of failure. Such a procedure can easily lead to both random errors by one operator and systematic errors among operators. With automatic turnoff and recording of the tachometer output, the maximum spin rate attained by the tester is accurately recorded for each sample. This system greatly reduces the possibilities for operator error.

Limited sample volume.--Sommerfeld (1971) has shown that, in the type of brittle failure which occurs in the centrifugal tensile tester, the distribution of measured strengths is a function of the volume tested. To predict failure stresses of large volumes, it is necessary to know the distribution of the weakest strengths. The older tester used a tube smaller in diameter than an appreciable number (about 10 percent) of the largest flaws. Since the largest flaws determine the weakest strengths, it was desirable to design a tester which could accept significantly larger samples.

Excessive sample handling.--In operating the older tester, the sample was pushed from the sampling tube into a similar tube fixed to the machine. This operation often disturbed the lower density samples. Therefore, the new tester was designed so that the sampling tube could be placed directly on the machine without transferring the sample.

Small notch radius.--The older tester used a notcher with a 1/4-inch radius, both to retain the sample and insure that it broke in the center. It is possible that this small radius caused excessive stress concentrations and erroneous measurements. The new design incorporates notchers of 3-inch radius.

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[1] *Geologist and Electronics Technician, respectively, Rocky Mountain Forest and Range Experiment Station, with central headquarters maintained at Fort Collins in cooperation with Colorado State University.*

Excessive vibration.--The older design depended on the motor bearing to hold the specimen tube. Because of the relatively light mounting, the machine vibrated in operation and the excessive vibration could have resulted in premature sample failure. The new design includes a massive turntable and large bearings, and is much smoother in operation.

Automatic Turn-Off

Eight photo-diodes (Raytheon CK 1241) [2] are mounted on the main panel on a circumference 1 inch outside the turntable edge (fig. 1). A light is mounted above each diode in a cover that can be removed for sample loading.

When the momentary start switch (Sw 2, fig. 2) is pressed, silicon controlled rectifier (SCR) No. 1 (G.E.C.-C30D) is gated, putting approximately 160 v.d.c. across the motor. When a sample of snow breaks, it blocks the light from one or more of the diodes. The resistance of a diode, when clear, is 2K ohms, and when blocked is 200K ohms. The increased resistance of the diode string raises the base voltage of the transistor (G.E.C. 2N335A) above its turn-on level (.3v). This in turn raises the gate voltage of SCR No. 2 (G.E.C.-C30D) above .8v, turning it on. With SCR No. 2 in a conducting capacitor state, C1 discharges through the 150 w. load light, putting an equal potential on both sides of SCR No. 1 and turning it off. Since voltage is no longer applied to the motor, it stops. Turn-off time is $3\text{x}10^{-3}$ sec., much faster than an operator's reaction time.

Tachometer

The drive motor also drives a d.c. tachometer (Electric Indicator Co. CB-247), whose output voltage is directly proportional to r.p.m. This voltage is recorded on a strip-chart recorder (Esterline-Angus Speed-servo) eliminating a possible source of operator error. The output can also be read on a meter dial.

Removable Sample Holder

Figure 3 shows the main features of the turntable, notchers, and sample holder. The sample holders were made from 5-inch (127 mm) o.d. 1/8-inch (3.2 mm) wall aluminum tubing. They are 7-7/8 inches (200 mm) long and contain

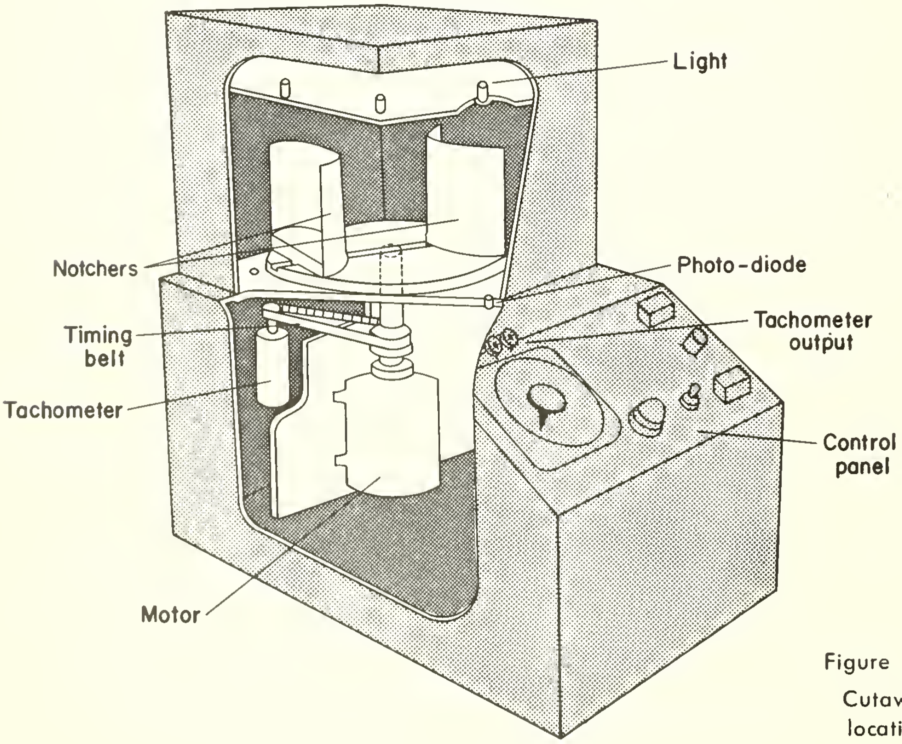

Figure 1.—
Cutaway view of spin tester showing location of various components.

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[2] *The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.*

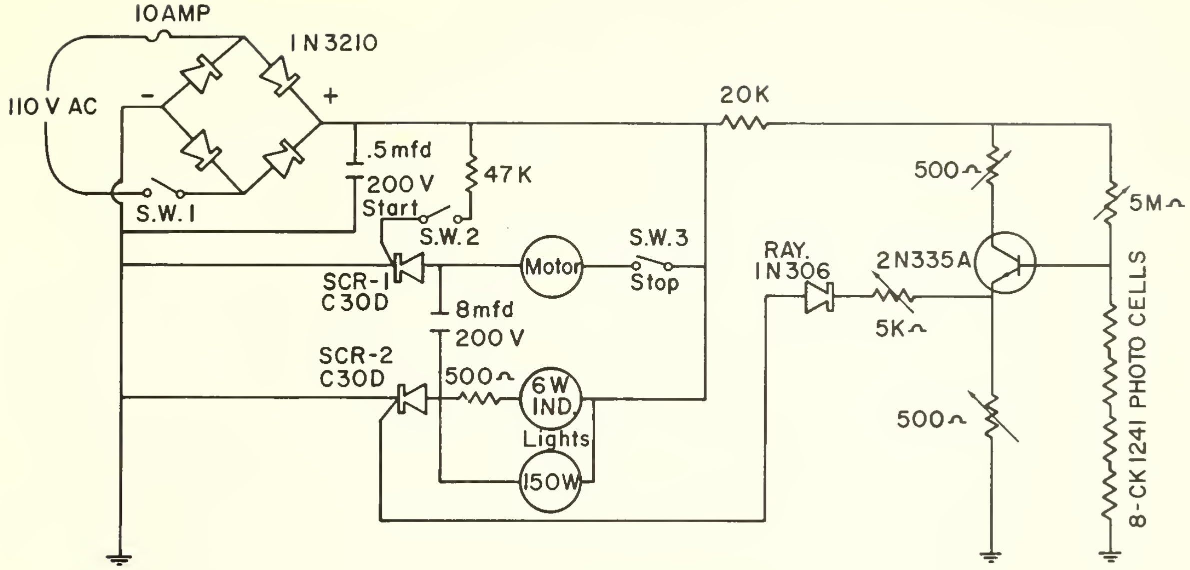

Figure 2.—Circuit diagram of start-stop circuit.

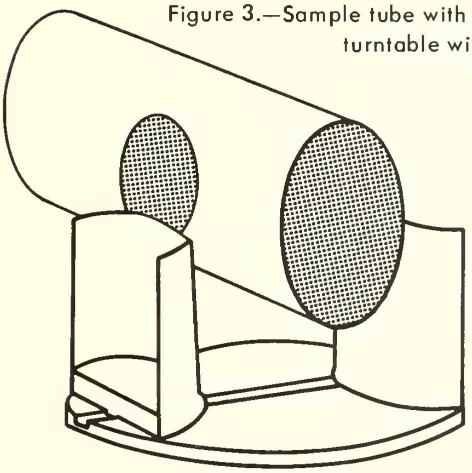

Figure 3.—Sample tube with cutouts and turntable with notchers.

a volume of 139.54 cubic inches (2.2867 x $10^{-3}m^3$) before notching. The width between the notches is 4.20 inches (10.67 mm).

Samples are cored from the sidewalls of pits with the sample holders. The holders are capped with plastic caps, carried inside, and weighed. When a holder is slipped between the notchers, the sharp edges of the notchers cut the snow sample, forming a narrowed cross section. An elastic band (not shown) is snapped across the holder to insure that it will not slip off. With the plastic caps removed from the holder, the sample is ready for testing. Since the sample is never removed from the holder it is much less susceptible to damage.

Larger Notch Radius

The narrow notchers of the older tester may have caused excessive stress concentrations. The 3-inch radius notchers on the new machine have stress concentration factors less than half those of the smaller notchers. Furthermore, the stress distribution in the centrifugal tester would make the difference even larger, since the effective notch length, in the nonuniform stress field, would decrease with the notch radius.

Smoother Operation

The excessive vibration experienced with the older tester has been eliminated by:

1. Using a massive turntable to support the sample holder. The turntable was carefully balanced so that its center of rotation corresponds to its center of mass and it rotates smoothly. Because of the large mass of the turntable, even large inhomogeneities in the snow sample do not throw the system seriously out of balance. A further advantage is that variations in sample weight are insignificant compared to the total inertia of the system, so that the rate of stress application is very nearly the same for all samples.

2. Using large, close-fitting bearings. These large bearings position the turntable shaft accurately and aid in smooth rotation of the turntable.
3. Isolating the motor from the turntable. The motor (Bodine Electric Co. NSE-34) is mounted on vibration-isolating mounts. The motor shaft is coupled to the turntable with a rubber coupler so that vibrations of the armature are not readily transmitted to the turntable.
4. Using a rubber belt for the tachometer drive. The older tester used a fiber gear to drive the tachometer, which may have introduced additional vibrations. The new design uses a rubber timing belt which gives the same nonslip drive as a gear without excessive vibration.

Operational Tests

The new centrifugal tensile tester has now been used to test over 400 samples. A flexible sheet of plastic was added over the control panel to prevent water from dripping into the panel. No other operational difficulties have occurred.

There have been no zero strengths in the 400 samples, indicating that the large sample diameter is larger than any possible flaw. Also, the larger tubes are much easier to use and do not appear to disturb the snow as much as the smaller tubes used previously.

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