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ROOTING WESTERN WHITE PINE, *PINUS MONTICOLA* DOUGL., NEEDLE FASCICLES AND BRANCH CUTTINGS

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ABSTRACT

Three experiments were conducted to investigate effect [illegible] BA, kinetin, GA_3, B-nine, sucrose, and of an acid and a base on [illegible]ting of western white pine needle fascicles and branch cuttings. [illegible] [illegible]ine, sucrose, and acid were all effective in enhancing root initiation.

KEYWORDS: Vegetative propagation, rooting, rooting white pine, rooting needle fascicles

Clonal lines are useful for investigations of genetics, physiology, and disease and insect resistance. Asexual propagation by cuttings is preferable to grafting because rootstocks can affect the development of grafted scions. Cuttings of western white pine (*Pinus monticola* Dougl.) are relatively difficult to root. Cuttings from seedlings up to 2 years of age root relatively well without any chemical treatment. With an auxin treatment, a rooting success of 75 to 100 percent is quite common. McDonald and Hoff (1969), and Hoff and McDonald (1968), rooted needle fascicles from western white pine seedlings. Toda and Isikawa (1971) reported that needle fascicles have the same trend in rooting in relation to age of the ortet as stem cuttings. Because of the small size and ease of handling, needle fascicles are ideal for larger studies to be carried out in growth chambers. However, western white pine and pines in general outgrow the capability of forming adventitious roots relatively fast beyond 2 years of age. According to Girouard (1971), there are few reports of rooting cuttings taken from pine trees over 10 years of age. However, because young seedlings have a limited number of branches for taking cuttings, development of clonal lines takes considerable time. Therefore present investigations were undertaken to find a combination of chemical treatments that enhance the rooting of cuttings from older trees.

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Previous research suggests that synthetic auxins promote rooting of pine cuttings. IBA, IAA, IPA and NAA[2] are several of the auxins that have been used to promote rooting; IBA seems to be the most effective (Girouard 1971). Even though cytokinins are known to be essential for cell division and differentiation; their effect on rooting is unknown. It has been found that a low auxin:cytokinin ratio favors bud initiation; a high auxin:cytokinin ratio favors root initiation.

Synergistic effects of chemicals were noted by Larsen and Dingle (1969) who reported that kinetin alone was not effective in initiating roots, but when added with IBA it did have a positive influence on rooting. Gibberellic acid has been shown to inhibit root formation in several species (Bachelard 1965; Brian and others 1960; Hassig 1972), and recently Smith (1974) reported that gibberellic acid inhibited root formation in *Pinus radiata* if it was applied before initiation began. Hare (1974) found the growth retardant B-nine[3] was effective in promoting rooting in pine.

When a cutting is severed, its supply of nutrients is cut off; therefore the supply of nutrients and carbohydrates must be adequate to supply energy and tissue-building requirements until a new root system can be established. Mergen and others (1958) concluded from the literature that rooting is augmented by endogenous food supply, although effects are confusing. Went and Thimann (1937) reported several sugars had a positive effect on root initiation. Thimann and Delisle (1939) advocated a sugar treatment for rooting most hard-to-root species. In addition, captan, a fungicide, augments rooting. Grigsby (1965) and others have reported benefits in using captan or other fungicides in rooting pines. Doran (1957) observed that captan with IBA or NAA increased rooting over either IBA or NAA alone. Van Elk (1969) found that treatment with captan increased rooting an average of about 20 percent. And finally, Lee and others (1977) advocated using an acid or base pretreatment to enhance rooting in certain species; acid pretreatment promoted rooting of plants native to neutral or alkaline soil, and a base pretreatment increased rooting ability of those plants native to acid soil.

The purpose of this paper is to report on three different studies designed to:

1. Ascertain the root-promoting influence of exogenously applied IBA, kinetin, and gibberellic acid alone and in combination on western white pine fascicles and cuttings.

2. Ascertain the root-promoting influence of IBA, sucrose, and the growth retardant B-nine alone and in combination on western white pine fascicles and cuttings.

3. Ascertain the root-promoting influence of several chemical treatments in combination with pretreatments of hot water, acid, or base on western white pine fascicles and cuttings.

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[2]IBA is indolebutyric acid, IAA is indoleacetic acid, IPA is indolepropionic acid, and NAA is napthaleneacetic acid.

[3]B-nine is N-dimethylaminosuccinamic acid.

MATERIALS AND METHODS

Experiment No. 1

The first study was set up to test the effects and interactions of three levels each of gibberellic acid (GA_3), indole-3-butyric acid (IBA), and kinetin (K) in all possible combinations on adventitious root development of adult and juvenile needle fascicles. Juvenile material was taken from 1-year-old seedlings and adult material was taken from two 20-year-old trees.

Cuttings were taken in early January from the lower lateral branches of the adult trees. Because the temperature was -15° C, the cuttings were placed in plastic bags, brought into a cool greenhouse (2° C) and thawed out overnight. The following morning fascicles were cut off the current year's growth with a razor blade, dipped in rooting powder, and planted in flats containing a sand:soil:peat moss (1:1:1) rooting medium. The investigations were carried out in growth chambers (55 cm x 125 cm inside dimensions) with 16-h photoperiods and a day/night temperature of 24°/10° C. Light intensity was 1 460 $\mu w/cm^2$ (as measured with an ISCO model SR spectroradiometer) from cool white fluorescent plus incandescent lights. Cuttings were watered once each day with a mist nozzle on a hose. The experiment lasted 120 days at which time all of the fascicles were removed and checked for rooting.

Rooting powders used contained GA_3 (0, 0.2, or 1 mg/gm), IBA (0, 5, or 20 mg/g), and K (0, 5, 15 mg/gm) in all possible combinations. The powders were prepared by dissolving the chemicals in 100 percent ethyl alcohol to which talc powder was added to make a slurry. The slurry was dried, ground in a mortar, and seived through a 100-mesh screen.

The experimental design was a randomized block with 25 fascicles/replication and two replications. Statistical analysis was carried out with factorial analysis of variance using percentages transformed by arc sin $\sqrt{\%}$ according to Snedecor (1956).

Experiment No. 2

In February 1974, a second study was initiated to investigate effects and interactions of two levels of IBA (0, 100 mg/liter), three levels of the growth retardant B-nine (0, 100, 200 mg/liter), and three levels of sucrose (0, 1, 2 g/liter) on both adult and juvenile needle fascicles. The same sources of material were used in this study as were used in the first study. On February 4, scions were collected from the adult ortets and handled the same as before. All conditions were the same as the first study except: (1) the rooting media was 1:1:2 (soil:sand:peat moss), (2) a 24-h soak was used instead of powder, and (3) following treatment all cuttings were dipped in 4 percent captan powder.

The experimental design was a randomized block with 25 fascicles/replication and four replications. Treatment design was a 3^3 factorial with two replications and 25 needle fascicles per treatment. Statistical analysis was carried out with factorial analysis of variance using percentages transformed by arc sin $\sqrt{\%}$ according to Snedecor (1956).

Experiment No. 3

Experiment 3 was set up to test the effects and interactions of four pretreatments and five treatments on adventitious root development of juvenile branch cuttings. On February 1, 1978, a single scion was collected from each of 280 6-year-old seedlings in nursery beds at the Moscow laboratory. Scions were placed in plastic bags and stored in a refrigerator overnight. Scions were trimmed to a length of 8 to 10 cm, bases were cut diagonally with pruning shears, treated, and stuck in 65 cm^3 Leach pine cell plastic containers containing a 2:2:1 (sand:peat:forest soil) rooting medium. The trial was conducted in a moist greenhouse rooting chamber with natural light and daylength. A spray-type watering system soaked the entire bench 1 minute out of each hour from 11:00 a.m. to 4:00 p.m. each day. The trial lasted 142 days, at which time the cuttings were removed and checked for roots. A split-plot design was used with 7 scions per treatment, replicated twice. All treatments were included in each pretreatment.

Pretreatments were: (1) 10-minute soak in cold water; (2) 10-minute soak in hot (50° C) water; (3) 10-minute soak in NaOH, pH 10.5; (4) 15-second dip in 2N H_2SO_4.

Treatments were:

1. 24-hour soak in water.

2. 24-hour soak in 50 ppm IBA + 1 g/liter sucrose.

3. 24-hour soak in 100 ppm IBA + 1 g/liter sucrose.

4. 0.8 percent IBA in 10 percent captan powder.

5. 0.8 percent IBA, 1 percent B-nine, 10 percent powdered sugar, 10 percent captan powder.

Treatments 1, 2, and 3 were dipped in 10 percent captan prior to sticking.

RESULTS AND DISCUSSION

Experiment No. 1

No adult needle fascicles rooted. Thus, only average rooting percentages for the juvenile fascicles are given in table 1. Analysis of variance indicate that GA_3 was the only growth substance treatment that was significant. The presence of GA_3 in the rooting powder significantly reduced rooting below that of non-treat cuttings. This is consistent with what Smith (1974) reported for *Pinus radiata*. However, IBA appears to be able to overcome some of the inhibition but not significantly. Kinetin was ineffective in counteracting the GA_3 effect.

Although effects of kinetin and IBA were not statistically significant (table 1), both appeared to enhance rooting either separately or together. When GA_3 was absent, all treatments except one exceeded the control. That treatment was a combination of the highest levels of both kinetin and IBA. This is in agreement with Larsen and Dingle (1969) who reported that kinetin enhanced rooting of *P. contorta*, but is inconsistent with Smith (1974) who reported that kinetin inhibited rooting of *P. radiata*. However, the concentration Smith worked with was selected due to its inhibitory effect. At lower concentrations he found no significant effects. Heide (1965) reported that 13 ppm kinetin promoted buds and inhibited rooting of begonia while 0.8 ppm stimulated the effect of IAA in root promotion.

Table 1.--*Average percentage rooted needle fascicles of 1-year-old western white pine from two replications with 25 fascicles per replication*

Treatment: Kinetin	Treatment: IBA	Treatment: GA_3[2]	Average rooting[1]
- - - - - - - - *mg/g*	- - - - - -	- - - - - -	*Percent*
0	0	5	2
0	0	20	2
1	0	20	2
1	5	20	2
0.2	0	20	4
.2	5	20	4
.2	15	20	4
.2	0	5	6
0	5	20	8
0	15	20	8
1	0	5	8
1	15	20	8
.2	5	5	12
1	5	5	12
1	15	5	16
0	5	5	22
.2	15	5	22
1	15	0	26
0	0	0	32 Control
0	15	5	32
1	5	0	40
0	5	0	46
.2	0	0	48
0	15	0	50
.2	5	0	50
1	0	0	58
.2	15	0	60

[1]Averages not connected by the same line are significant at the 5-percent level according to Duncan's new multiple range test.

[2]Analysis of variance showed significant difference for GA_3 treatments at 1-percent level.

Thus, the results here indicate that kinetin at least is not inhibitory to rooting of western white pine and could possibly be a stimulant.

Experiment No. 2

Because the rooting response of juvenile and adult needle fascicles varied so much, this study was analyzed as two separate experiments. The overall rooting success was considerably lower with the adult needle fascicles than with juvenile fascicles (tables 2 and 3).

Table 2.--*Treatments and average rooting percentages for adult western white pine needle fascicles; ranked in order of increasing rooting success*

IBA[3]	B-nine	Sucrose	Average rooting[1]	
- - - *mg/l* - - - - -		*g/l*	*Percent*	
0	0	0	[2] 0	
100	100	1	11	
100	100	0	12	
100	100	2	13	
100	200	1	14	
100	200	0	15	
100	200	2	16	
0	200	2	17	
100	0	1	18	
0	200	0	22	
100	0	2	22	
0	100	2	23	
0	0	2	24	
0	200	1	24	
0	0	0	26	Control
100	0	0	27	
0	100	1	28	
0	0	1	32	
0	100	0	33	

[1]Averages not connected by the same line are significant at the 5-percent level according to Duncan's new multiple range test.
[2]Needle fascicles of all treatments except this control were dipped in 4-percent captan prior to sticking.
[3]Analysis of variance showed significant difference for IBA treatments at 1-percent level.

Table 3.--*Treatments and average rooting percentages for juvenile western white pine needle fascicles; ranked in order of increasing rooting success*

IBA[3]	B-nine	Sucrose[4]	Average rooting[1]	
- - - - *mg/l* - - - -		*g/l*	*Percent*	
0	0	0	[2] 10	
100	200	2	13	
100	200	0	25	
100	100	2	29	
100	100	0	32	
100	0	2	34	
0	0	0	39	Control
0	100	2	39	
0	200	2	39	
0	0	2	41	
100	200	1	41	
0	200	0	42	
100	100	1	52	
0	100	1	54	
100	0	1	57	
100	0	0	58	
0	100	0	63	
0	200	1	66	
0	0	1	84	

[1]Averages not connected by the same lines are significantly different at the 1-percent level according to Duncan's new multiple range test.
[2]Needle fascicles of all treatments except this control were dipped in 4-percent captan prior to sticking.
[3]Analysis of variance showed significant difference in IBA treatments at 5-percent level.
[4]Analysis of variance showed significant difference in sucrose treatments at 1-percent level.

According to the analysis of variance for the adult needle fascicles, IBA was the only significant treatment, but further analysis with Duncan's new multiple range test (Duncan 1955) (table 2) indicates some other differences also. IBA in general is significantly poor, especially in combination with B-nine. No IBA treatment significantly improved rooting, and in combination with B-nine and/or sucrose it had an inhibiting effect as compared to the captan treated control. On the other hand, B-nine and sucrose, individually or together, enhanced rooting at the intermediate level.

Analysis of data for juvenile needle/fascicles shows significant differences due to levels of IBA and sucrose. Also, there was a significant interaction of the three substances. Further analysis with Duncan's new multiple range test (table 3) shows that when the level of IBA used was combined with higher levels of either B-nine or sucrose, there was no increase in rooting and in some cases rooting was reduced. However, when IBA was added to moderate levels of B-nine and sucrose there was a significant increase in rooting, but the best treatments did not include IBA. The best treatment was 1 g/liter sucrose by itself.

Although the magnitude of response to the various treatments is much smaller in the adult than juvenile needle fascicles, there are several similarities between the two groups. For example, the least rooting in either juvenile or adult fascicles occurred in the control without captan. In both cases the survival of needle fascicles was good; therefore, it was concluded that captan does enhance rooting of western white pine, and the fungicidal effect may be minimal. Needle fascicles in both categories rooted best without auxin treatment, and either sucrose or B-nine effectively replaced IBA for enhancing root initiation.

Deuber (1942) reported that cuttings from 6-year-old eastern white pine treated with 1.5 percent sucrose rooted about the same as those given IBA alone, but those treated with IBA plus sucrose rooted about the same as the controls. The results here show a similar response to sucrose, i.e., sucrose alone is better than sucrose plus IBA. However, the results of this study vary for both juvenile and adult material. As stated above, the best treatments for both categories was without IBA. Also, sucrose alone was better than IBA in both cases, but IBA alone enhanced rooting of juvenile but not adult fascicles. The effect of IBA plus sucrose was the same as IBA alone for juvenile but considerably lower for the adult fascicles.

These results indicate that western white pine needle fascicles may contain enough endogenous auxin for root initiation but initiation is limited due perhaps to gibberellin inhibition or lack of energy. Thus, when sucrose and/or B-nine are added at or near the proper level root initiation can occur.

Experiment No. 3

The effects of hormone treatments on the rooting of western white pine stem cuttings were significant at the 0.5 percent and pretreatment effects were signficant at the 12 percent level (table 4). The interaction of treatments with pretreatments was nonsignificant.

Table 4.--*Analysis of variance for data in table 5*

Source of variation	Degrees of freedom	Mean squares	F
Blocks	1	422.50	2.97 ns
Pretreatments (A)	3	696.90	4.90*
Error (a)	3	142.23	
Treatments (B)	4	1,446.19	42.92**
Interaction (AB)	12	260.34	0.77 ns
Error (b)	16	336.55	
Total error	19	305.87	
Total	39		

* Significant at the 12-percent level.
** Significant at the 0.5-percent level.
ns=Nonsignificant.

Treatments 3 (24-h soak in 100 ppm IBA + 1 g/liter sucrose), 4 (0.8 percent IBA in 10 percent captan powder), and 5 (0.8 percent IBA, 1 percent B-nine, 10 percent powdered sugar, 10 percent captan powder) gave the best response (table 5). The best pretreatments were H_2SO_4 (15-second dip in 2N H_2SO_4) and NaOH (10-minute soak in NaOH, pH 10.5). The best combinations were H_2SO_4 pretreatment followed by treatment 5 or 4, respectively. This enhancing effect of H_2SO_4 is contrary to the findings of Lee and others (1977). They reported that in general an acid pretreatment promoted rooting of plants native to near neutral or alkaline soil and base pretreated cuttings increased rooting of those native to acid soil. Since western white pine is native to acid soil, they would have predicted the base to be best, which is what happened when hormone treatment 3 was used. Therefore, it appears that the pretreatment interacts with the hormone treatment and specific combinations should be selected for optimum rooting.

CONCLUSIONS

Western white pine juvenile material, at least up to 6-year-old trees, can be rooted with sufficient frequency to propagate clonal lines for research. However, except for needle fascicles, we have not been able to root adult material. Results from rooting adult needle fascicles may give some clues as to what is required for rooting adult branch cuttings.

Table 5.--*Average percent rooting of cuttings of 6-year-old western white pine*

Pretreatment	Hormone treatment[1]					
	1	2	3	4	5	Average
Cold water	0	7.0	28.5	14.0	35.5	17.0
Hot water	14.5	14.0	36.0	21.5	29.0	23.0
NaOH	14.0	21.5	50.0	43.0	28.5	31.4
H_2SO_4	7.0	21.5	28.5	57.0	64.0	35.6
Average	8.9	16.0	35.8	33.9	39.2	26.75

[1]Treatments were:

1. 24-hour soak in water.
2. 24-hour soak in 50 ppm IBA + 1 g/liter sucrose.
3. 24-hour soak in 100 ppm IBA + 1 g/liter sucrose.
4. 0.8 percent IBA in 10 percent captan powder.
5. 0.8 percent IBA, 1 percent B-nine, 10 percent powdered sugar, 10 percent captan powder.

Treatments 1, 2, and 3 were dipped in captan prior to sticking.

Gibberellins have been implicated as being involved in the aging and (or) maturing process in plants. Experiment 1 showed that GA_3 inhibits rooting of very young western white pine, which agrees with what Smith (1974) reported for *Pinus radiata*. The second experiment showed that the growth retardant B-nine (which acts as an antigibberellin) promotes rooting in adult and juvenile needle fascicles. In Experiment 3, one of the best hormone treatments for inducing rooting in branch cuttings from 6-year-old trees included B-nine. Therefore, it appears that gibberellins may be inhibiting rooting in western white pine and the use of B-nine may help produce a hormonal balance favorable for rooting. Hare (1974) has reported similar results with southern pines.

The effect of kinetin on rooting western white pine was inconclusive. Although it appeared to enhance rooting of juvenile needle fascicles it was not significantly different from the control. However, the results of Experiment 1 would indicate that at least at the levels used kinetin does not inhibit rooting.

Although IBA is effective in promoting rooting in juvenile white pine and most other plants, it has not been effective by itself in rooting cuttings in older western white pine. Results of Experiment 2 with adult needle fascicles indicate that the endogenous auxin level may be adequate and that the limiting factor may be inhibition by gibberellins or low available energy reserves, or both. Sucrose, at moderate levels, promotes rooting in both needle fascicles and stem cuttings, but at higher levels it appears to be inhibitory. At 1 g/liter, it stimulated rooting of both juvenile and adult needle fascicles more than the IBA treatments, but at 2 g/liter rooting was less than the control. Sucrose alone was a better rooting stimulant than sucrose plus IBA. These results are similar to those of Deuber (1942), who found that cuttings of 6-year-old eastern white pine treated with 1.5 percent sucrose rooted about the same as IBA alone, but IBA plus sucrose rooted about the same as the controls. The balance of auxins:gibberellins:carbohydrates and other growth substances necessary for root initiation is critical and only slight alteration of any one may induce or inhibit rooting.

Lee and others (1977) found that cuttings from acid loving plants rooted better when pretreated with a base. The results here were not as conclusive. The two best combinations of pretreatments:treatments included an acid pretreatment, but one base pretreatment plus hormone treatment was almost as good. Therefore, specific combinations should be selected for optimum rooting.

An added observation in Experiment 2 was the benefits of using captan fungicide. The use of captan increased rooting 26 and 29 percent, respectively, for adult and juvenile needle fascicles over that of controls without captan. This effect had previously been reported by Van Elk (1969) who noted a 20 percent increase with captan.

The following treatments are recommended for rooting cuttings of western white pine up to 6 years old: (1) pretreat for 15 seconds with 2N H_2SO_4; (2) treat with a rooting powder containing 0.8 percent IBA plus 10 percent captan, or 0.8 percent IBA, 1 percent B-nine, 10 percent powdered sugar, and 10 percent captan powder. Either powder should give good results and the 0.8 percent IBA 10 percent captan is much simpler to make up. No recommendation can be made for rooting adult branch cuttings; however, Toda and Isikawa (1971) reported that needle fascicles show the same response in rooting in relation to age of the ortet as stem cuttings. Thus, from the experiment with adult needle fascicles, the best treatment for adult cuttings may be B-nine, sucrose, or both without auxin.

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REFORMULATION OF FOREST FIRE SPREAD EQUATIONS IN SI UNITS

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ABSTRACT

The basic fire spread equations published by Rothermel in 1972 are reformulated in the International System of Units.

KEYWORDS: fire spread, equations, Rothermel's model, the International System of Units

Rothermel's paper (1972) describing a mathematical model for predicting fire spread in wildland fuels is the basis for several fire management systems. That paper also defines fire parameters that are the subject of continuing research and refinement.

Van Wagner (1978) suggested a list of metric units and conversion factors of practical suitablity for forest fire operational work following the approved standards of the International System of Units (SI).

Heretofore, when SI units have been required of the Rothermel model, the input metric parameters were converted to British units, the calculations performed in the British standard, and then the output parameters reconverted to SI units--a cumbersome procedure.

This research note presents a reformulation in SI units of the basic fire spread equations summarized on pages 26 and 27 of Rothermel's original paper. The first list defines the input parameters in metric units as required and used in the succeeding list of fire spread equations. Also listed are the significant output parameters with their resulting metric units. Standard SI nomenclature for units and symbols is assumed (National Bureau of Standards 1975).

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INPUT/OUTPUT PARAMETERS FOR BASIC EQUATIONS IN METRIC FORM

Input

w_o	Ovendry fuel loading, kg/m^2
δ	Fuel depth, m
σ	Surface area:volume ratio, cm^{-1}
h	Fuel heat content, kJ/kg
ρ_p	Fuel particle density, kg/m^3
M_f	Fuel moisture content, dimensionless fraction
S_T	Fuel total mineral content, dimensionless fraction
S_e	Fuel effective mineral content, dimensionless fraction
U	Windspeed at midflame height, m/min
$\tan\phi$	Slope (verticle rise/horizontal run), dimensionless fraction
M_x	Fuel moisture of extinction, dimensionless fraction

Output

R	Spread rate, m/min
I_R	Reaction intensity, $kJ/(min \cdot m^2)$
I_B	Byram's intensity, kW/m
L_f	Flame length, m

SUMMARY OF BASIC FIRE SPREAD EQUATIONS

IN SI UNITS

Equation 52 Formulation is unchanged; the units for *spread rate* are meters per minute.

$$R = \frac{I_R \xi (1 + \phi_w + \phi_s)}{\rho_b \varepsilon Q_{ig}}$$

Equation 27 Formulation is unchanged; the units for *reaction intensity* are $(kJ/min)/m^2$.

$$I_R = \Gamma' w_n h \eta_M \eta_s .$$

For those who prefer kilowatts per square meter (kW/m^2) for units of reaction intensity, use

$$I_R = \frac{1}{60} \Gamma' w_n h \eta_M \eta_s .$$

However, when this form is used in equation 52 above, the units for spread rate are meters per second.

Equation 38 The *optimum reaction velocity* is unchanged in formula or units (min^{-1}). However, for easier calculation, some prefer the following:

$$\Gamma' = \Gamma'_{max}\left[\frac{\beta}{\beta_{op}} \exp(1 - \frac{\beta}{\beta_{op}})\right]^A .$$

Equation 36 The *maximum reaction velocity* units remain min^{-1}; the formula becomes

$$\Gamma'_{max} = (0.0591 + 2.926\sigma^{-1.5})^{-1} .$$

Equation 37 The *optimum packing ratio* is dimensionless; the formula becomes

$$\beta_{op} = 0.20395\sigma^{-0.8189} .$$

Equation 39 Remains dimensionless; the original Rothermel formulation becomes

$$A = (6.7229\sigma^{0.1} - 7.27).$$

However, the (dimensionless) metric form used in the computer based library of fire behavior routines (Albini 1976) is

$$A = 8.9033\sigma^{-0.7913} .$$

Equation 29 The *moisture damping coefficient* (dimensionless fraction) is unchanged:

$$\eta_M = 1 - 2.59 \frac{M_f}{M_x} + 5.11\left(\frac{M_f}{M_x}\right)^2 - 3.52\left(\frac{M_f}{M_x}\right)^3 .$$

Equation 30 The *mineral damping coefficient* (dimensionless fraction) is unchanged:

$$\eta_s = 0.174 s_e^{-0.19}$$

Equation 42 The *propagating flux ratio* is a dimensionless fraction; the metric formulation is

$$\xi = (192 + 7.9095\sigma)^{-1} \exp\left[(0.792 + 3.7597\sigma^{0.5}) (\beta + 0.1)\right] .$$

Equation 47 The *wind coefficient* is dimensionless; the metric formula is

$$\phi_w = C(0.3048U)^B\left(\frac{\beta}{\beta_{op}}\right)^{-E} .$$

Equation 48 Becomes

$$C = 7.47 \exp(-0.8711\sigma^{0.55}).$$

Equation 49 Becomes

$$B = 0.15988\sigma^{0.54}.$$

Equation 50 Becomes

$$E = 0.715 \exp(-0.01094\sigma).$$

Equation 24 The *net fuel loading* units are kilograms per square meter; the preferred equation is now

$$w_n = w_o(1 - S_T).$$

Equation 51 The *slope factor* is dimensionless and unchanged:

$$\phi_s = 5.275\beta^{-0.3}(\tan \phi)^2.$$

Equation 40 The *ovendry bulk density* has no change in formula; the units are kilograms per cubic meter:

$$\rho_b = w_o/\delta$$

> If fuel depth, δ, is measured in centimeters, the alternative form for bulk density (in kilograms per cubic meter) is $\rho_b = 100w_o/\delta$.

Equation 14 The *effective heating number* is dimensionless; the metric form is

$$\varepsilon = \exp(-4.528/\sigma).$$

Equation 12 The *heat of preignition* units are (kJ/kg); the metric formula is

$$Q_{ig} = 581 + 2594M_f.$$

Equation 31 Packing ratio is dimensionless and remains unchanged:

$$\beta = \rho_b/\rho_p.$$

The metric equation for Albini's formulation of *Byram's fireline intensity* may be of interest:

$$I_B = \frac{1}{60} I_R R(11700/\sigma).$$

The units of I_B are kilowatts per meter of fire line. (Note: The factor $\frac{1}{60}$ may be omitted if the alternative form of equation 27 is used.) His estimate of *flame length*, L_f, becomes

$$L_f = 0.237 I_B^{0.46} \text{ meters}.$$

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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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POSTHARVEST RESIDUE BURNING UNDER ALTERNATIVE SILVICULTURAL PRACTICES

Robert W. Steele[1]

ABSTRACT

Prescribed burning of logging slash was done in clearcut, overstory removal, and understory cutting units in a Douglas-fir stand on the Lubrecht Experimental Forest near Missoula, Mont. The burning prescriptions and actual burning conditions are described. Data on preharvest, postharvest, and postburn conditions are reported.

KEYWORDS: prescribed burn, fire, fuels management, logging slash

INTRODUCTION

Timber harvesting activities in western Montana coniferous forests leave varying amounts of wood residue after the merchantable products have been removed. Burning is a common means of treating these residues. In addition to consuming the smaller fuels and thus reducing the fuel hazard, burning is an effective means of site preparation for regeneration. It also stimulates plant nutrient release in the soil. Partial cut silvicultural systems of harvesting could reduce fuel amounts or complicate burning to such an extent that burning logging debris becomes questionable as a logging site treatment. The more fuel that exists after logging, the greater the flexibility in prescribing slash burning. The use of burning as a slash treatment depends on the weight, depth, and size class distribution of fuels, and the constraints imposed by the silvicultural system selected for a given timber stand.

This study was conducted to determine the influence of three silvicultural practices on fuel availability and on the physical feasibility of postharvest slash burning. The study took place on the University of Montana's Lubrecht Experimental Forest and included three logged units, each receiving a different silvicultural treatment. These units are defined briefly as "overstory removal," where all trees over 9 inches d.b.h. were cut with an effort to leave a substantial understory stand; "understory removal," where the overmature trees were cut, the 5-9-inch d.b.h. class was thinned, and all trees less than 5 inches d.b.h. were removed and remaining stems slashed; and "clearcut," where merchantable material is removed and slash is left.

Table 1 shows the preharvest timber stand characteristics and table 2 the silvicultural prescription imposed on each cutting unit.

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Table 1.--*Stand characteristics (preharvest, Lubrecht Experimental Forest)*

Sawtimber: (9 inches d.b.h. +)	85 stems per acre (212 stems per hectare) One-half is over 120 years Three-fourths is Douglas-fir Heights range from 50-100 feet (15-30 meters)
Poles: (5-9 inches d.b.h. +)	115 stems per acre (288 stems per hectare) One-fourth is over 120 years Three-fourths is Douglas-fir Heights range from 30-60 feet (9-18 meters)
Saplings: (0.1-5 inches d.b.h.)	400 stems per acre (1,000 stems per hectare) Over three-fourths is Douglas-fir Heights range from 5-30 feet (1.5-9 meters)
Seedlings: (<0.1 inch d.b.h.)	2,000 stems per acre (5,000 stems per hectare) Almost all are Douglas-fir

Table 2.--*Silvicultural prescriptions (harvesting specifications, prescribed burn, Lubrecht Experimental Forest)*

			Stems per acre (per hectare)			
			Cut[1]		Leave[1]	
Prescription	Cutting specifications[1]		DF	PP and WL	DF	PP and WL
Understory removal	Cut only "older" trees >9 inches d.b.h.	Sawtimber (9 inches)	50 (125)	>0 (0)	15 (38)	<20 (50)
	Thin 5-9 inches d.b.h. favoring WL and PP	Poles (5-9 inches)	55 (138)	0 (0)	30 (75)	<30 (75)
	Cut all trees <5 inches d.b.h.	Saplings (1-5 inches)	300 (750)	100 (250)	--	--
		Seedlings (4 ft)	2,000 (5,000)	--	--	--
Overstory removal	Cut all 9 inches d.b.h.	Sawtimber	65 (163)	20 (50)	--	--
	Cut all DF 5-9 inches d.b.h. and thin remaining WL and PP if needed.	Poles	85 (170)	0 (0)	--	<30 (75)
	Thin trees 5 inches d.b.h., favoring DF	Saplings	225 (563)	75 (188)	75 (188)	25 (63)
		Seedlings	1,850 (4,625)	--	150 (375)	--
Clearcut	Clearcut all merchantable material	Sawtimber	65 (163)	20 (50)	--	--
	Slash remaining material	Poles	85 (170)	30 (75)	--	--
		Saplings	300 (750)	100 (250)	--	--
		Seedlings	2,000 (5,000)	--	--	--

[1]DF = Douglas-fir
PP = Ponderosa pine
WL = Western larch.

The area was logged in summer 1977 using crawler tractors for skidding. The stand remaini after harvest is summarized in table 3. Prescribed burning was done in late summer 1978, after one season of slash curing. Each silvicultural treatment poses a different set of burning constraints and each will be discussed separately.

Table 3.--*Lubrecht harvesting study postharvest stand table*

	Number of trees per acre							
	Overstory removal				Understory removal			
D.b.h.	DF	WL	PP	Total	DF	WL	PP	Total
2	272.3	2.3	2.3	276.9				
4	109.2	1.5	2.3	113.0				
6	42.3	2.3	--	44.6	10.7	--	1.4	12.1
8	20.8	6.9	--	27.7	11.3	--	--	11.3
10	.8	.8	--	1.6	12.0	--	--	12.0
12					4.7	1.3	--	6.0
14					6.7	.7	--	7.4
16					2.0	.7	--	2.7
18					4.0	1.3	--	5.3
21+					.7	--	.7	1.4
Totals	445.4 (1,113.5/ha)	13.8 (34.5/ha)	4.6 (11.5/ha)	463.8 (1,159.5/ha)	52.1 (130.3/ha)	4.0 (10.0/ha)	2.1 (5.3/ha)	58.2 (140.6/ha)

Clearcut

Slash from the harvesting consisted of some concentrations. Some cleared areas had no slash because of skid trails. The fuel bed contained 29 tons of dead fuel per acre (65 metric tons per hectare).

Burning slash in clearcut areas is designed to consume as much fuel as possible as a fire hazard reduction, add as many soil nutrients as possible from the ash, and provide as many regeneration sites as possible for starting new forest stands. The idea is to get a fire as hot as possible within the constraints of safety and confinement to the clearcut area. In this study, the following prescription seemed feasible to accomplish this:

Fine fuel moisture	10 - 18 percent
Temperature	60° - 80°F (15° - 27°C)
Relative humidity	20 - 60 percent
Windspeed	less than 12 mi/h (19 km/h)

Ignition pattern: Ignite the fire such that a concentration of heat will develop down the center of the area first, then ignite the edges so the fire will "pull in" toward the center.

Actual burning of this unit occurred under the following conditions:

Fine fuel moisture	18 percent
Temperature	84°F (29°C)
Relative humidity	18 percent
Wind velocity	2 mi/h (3.2 km/h)

The fire was ignited so that heat would develop rapidly in the center of the area. As the edges were later ignited, the flames pulled toward the center producing a tall straight convection column. The igniting took about 15 minutes. The fire burned intensely, rapidly consuming the fuel load; 64 percent of the dead fuel was consumed (table 4). The fire blackened the entire area except where skidding had removed all fuel down to the mineral soil. A variety of microsites were created for regeneration.

Table 4.--*Lubrecht harvesting study fuel data*

Fuel size class	Tons per acre					
	Preburn			Postburn		
	Clear-cut	Overstory Removal	Understory removal	Clear-cut	Overstory removal	Understory removal
0-1/4 inch	0.71	0.63	0.46	0.06	0.18	0.20
Percent consumed	--	--	--	92	71	57
1/4-1 inch	3.95	2.43	2.43	.53	1.11	1.36
Percent consumed	--	--	--	87	54	44
1-3 inches	4.84	7.26	4.84	2.03	3.41	3.38
Percent consumed	--	--	--	58	53	30
3 inches + sound	15.26	5.94	8.27	7.36	3.82	6.52
Percent consumed	--	--	--	52	36	21
3 inches + rotten	4.66	5.82	2.13	.74	.32	.52
Percent consumed	--	--	--	84	95	76
Total	29.42 (66.9 t/ha)	22.08 (49.6 t/ha)	18.13 (40.8 t/ha)	10.72 (24.1 t/ha)	8.84 (19.9 t/ha)	11.98 (26.85 t/ha
Percent consumed	--	--	--	64	60	34

Overstory Removal

The stand remaining after harvesting consisted of 464 trees per acre (1 160 per hectare), which contained 314 cubic feet per acre (23.6 cubic meters per hectare); 100 (250/ha) were selected as "leave" trees. These remaining trees were the smaller ones of the stand. Many of them between 5 and 11 inches d.b.h. had been suppressed by the overstory, but were considered the best available for developing the future stand.

The dead fuel accumulation on the forest floor plus slash from the cut trees amounted to 22 tons per acre (55 metric tons per hectare). This fuel lay in a fairly continuous mat, interlaced by skid trails on which no fuel existed.

To assure that the smaller isolated leave trees and clumps of seedling-sized trees a foot or so high would survive a slash disposal fire, limited rearrangement of this fuel was necessary Some hand piling helped reduce fuel concentration adjacent to leave trees and clumps of seedling The resulting fuel bed consisted of piles with scattered limbs and tops put in areas where no leave trees existed. This treatment took 5 man-days of effort for the unit, or 1.1 man-days per acre.

The job required of this prescribed fire was: (a) to eliminate the fire hazard in dead fuels less than 1 inch in diameter; (b) to provide some added soil nutrients from the ash; and (c) to limit its intensity and location should a wildfire occur so as to preserve the understory trees. This understory consisted of trees 5 inches d.b.h. and less as well as clumps of seedling-sized trees purposefully left after harvesting. In this situation, fire has a difficul role to play because the small trees and clumps of seedlings are not capable of tolerating much heat. Some degree of heat management can be accomplished by careful igniting procedures, and by burning under conditions close to the following prescription:

Fine fuel moisture	17 - 22 percent
Temperature	60° - 70°F (15° - 21°C)
Relative humidity	30 - 60 percent
Windspeed	4 - 8 mi/h (6.4 - 12.8 km/h)

Ignition pattern: Ignite in strips concentrating on piles of fuel and then wait for the heat to "pulse out" before igniting further fuel. Move the firing into the wind.

Actual burning of this unit occurred under the following conditions:

Fine fuel moisture	20 percent
Temperature	75°F (24°C)
Relative humidity	30 percent
Wind velocity	4 mi/h (6.4 km/h)

The fire was ignited on the uphill side first, then progressively down slope toward the road. The unit was considered as two separate parts because of the difference in terrain: the west was a slope, the east half flat. Igniting was complete on the west half before it was started on the east. Piles and concentrations of slash were ignited and allowed to "pulse out" in heat output before any further ones were ignited. This scheme functioned well and allowed us to manipulate the fire well enough to preserve most of the leave trees and some of the clumps of seedling-size Douglas-fir trees. Many of the clumps of seedling-size trees survived because there was almost no dead fuel present. Where concentrations of fuel existed, the fire burned all fuel and created some microsites for possible seedling establishment.

The conditions under which this fire was ignited allowed enough flexibility for fire manipulation so that close to desired results were possible. About half of the marked leave trees were killed from crown scorching and excess cambium heating, and some clumps of seedlings were lost. Many leave trees, however, were of low vigor and had sustained dead crown material from spruce budworm defoliation.[2] This probably increased their susceptibility to fire. The fire consumed 60 percent of the available fuel, including 95 percent of the rotten wood fuel (table 4).

Understory Removal

The stand remaining after harvesting consisted of 58 trees per acre (145 per hectare), containing 1,122 cubic feet per acre (84 cubic meters per hectare). These trees were reasonably well spaced and constituted a forest stand suitable for many years of continued growth.

The dead fuel accumulation on the forest floor plus that from the cut trees amounted to 18 tons per acre (40 metric tons per hectare) (table 4). This fuel, in an uneven array, had some concentrations piled around the standing leave trees.

In order to protect the leave trees from excessive heat, we rearranged some of it. Concentrations of slash fuel next to the leave trees were scattered, but no hand piling was done. This treatment resulted in a more even fuel bed but did not anywhere near make a completely uniform fuel bed. This treatment took 6 man-days for the unit, or 1.1 man-days per acre (2.75 man-days per hectare).

The job required of the fire here was: (a) to reduce the fire hazard by eliminating the fine fuels (up to 1 inch in diameter); (b) to add some nutrients to the soil from the resulting ash; and (c) to limit the intensity such that the leave trees would not be killed by cambium heating or by excessive scorch to the live crowns. This type of fire is possible if fuel and weather conditions are right and if care is taken during igniting. The following prescription was deemed suitable in this case:

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[2]Benson, Robert E. Damage from logging and prescribed burning in partial cut Douglas-fir stands. USDA For. Serv., Intermt. For. and Range Exp. Stn., Res. Note. [In press.]

Fine fuel moisture	18 - 25 percent
Temperature	60° - 70°F (15° - 21°C)
Relative humidity	30 - 60 percent
Windspeed	5 - 8 mi/h (8 - 12.8 km/h)

Ignition pattern: Ignite in strips that head at right angles to the prevailing wind and that move progressively into the wind.

Table 4 shows postburn fuel amounts and the percent of fuel consumed by size classes. The unusually low consumption of fuel in the understory removal unit resulted from the large proportion of tree boles and small amount of fine fuels plus high fuel moisture during the burn.

Actual burning of this unit occurred during the following conditions:

Fine fuel moisture	24 percent
Temperature	70°F (21°C)
Relative humidity	28 percent
Windspeed	0 mi/h

The fire was ignited in strips along the east side, then moved progressively west. It was necessary during this burn to buck up and pile some of the material to get a satisfactory burn. The fuel consisted largely of trees 3 to 5 inches in diameter that were suppressed much of their life and had little crown. This condition produced a small amount of fine fuels, resulting in many unburned pieces. Less than 5 percent of the marked leave trees were killed. About 25 percent had light crown or bole scorch.

Prescribed burning is feasible under standing timber where the slash is created by removing the understory trees. The fuel, however, is predominantly tree boles with a minimum of fine fuels. This condition makes it difficult to produce the lesser amount of heat desired for stand tree protection. Some fuel rearrangement is also needed because of the tendency for accumulatio of limbs and tops to occur adjacent to the standing trees. If the fire manager is willing to do limited fuel arrangement work ahead of burning and can wait for a day with the prescription conditions, such a practice is possible. The results of this experimental burn showed that only 34 percent of the total fuel was consumed (table 4). This rather low fuel consumption occurred because the burn was conducted at the "wet end" of the prescription limits and because of the limited amounts of fine fuel in proportion to the amount of larger fuel (3 inches +).

DISCUSSION

The use of fire for hazard removal and site preparation was evaluated in this study. Whil fire use necessitates having sufficient fuel to burn, it is also necessary to manipulate the fi for desired levels of heat output. In the three treatments--clearcut, overstory removal, and understory removal--where no fuel was added or removed after the harvesting, ample fuel existed for such burning.

The problem here was not with fuel amount, but with other constraints such as air quality restrictions and the close prescription limits for burning under standing trees. The study showed that when fuel composition lacks sufficient fine fuels, as it did in the understory removal unit, the fuel moisture needs to be lower for the adequate fuel consumption a suitable prescription would need. This condition makes it difficult to manage the fire so that scorchin and cambium heating can be kept at a suitable minimum. In the overstory removal unit there was suitable mixture of fine and larger fuels so that adequate fuel consumption was possible at the prescribed limits of fuel moisture. The problem here was that small leave trees and clumps of seedlings were killed easily by the fire.

The standard local constraints on prescribed burning for smoke management limit the days suitable for burning under standing timber more than they do for clearcut burning because of th need for higher fuel moisture. This limitation can be tolerated, however, and more experience will probably show it can be done under a wider variety of conditions than previously thought feasible.

We also need to recognize that, although using fire to prepare sites for continued timber production or for starting a new stand may be cheaper than other methods, it does require spending money for fuel bed preparation. This cost probably can be reasonable if fuel arrangement is limited to protecting the standing trees from obvious concentrations of fuels around their bases.

This study showed that clearcutting, overstory removal, and understory removal harvesting resulted in sufficient fuel for adequate prescribed fire. The fuel reduction was greatest in the clearcut and least in the understory removal, but was adequate to sufficiently reduce the fire hazard to acceptable levels (fig. 1). The cost of fuel manipulation and subsequent thinning was not excessive, at least on the relatively level ground where this study took place.

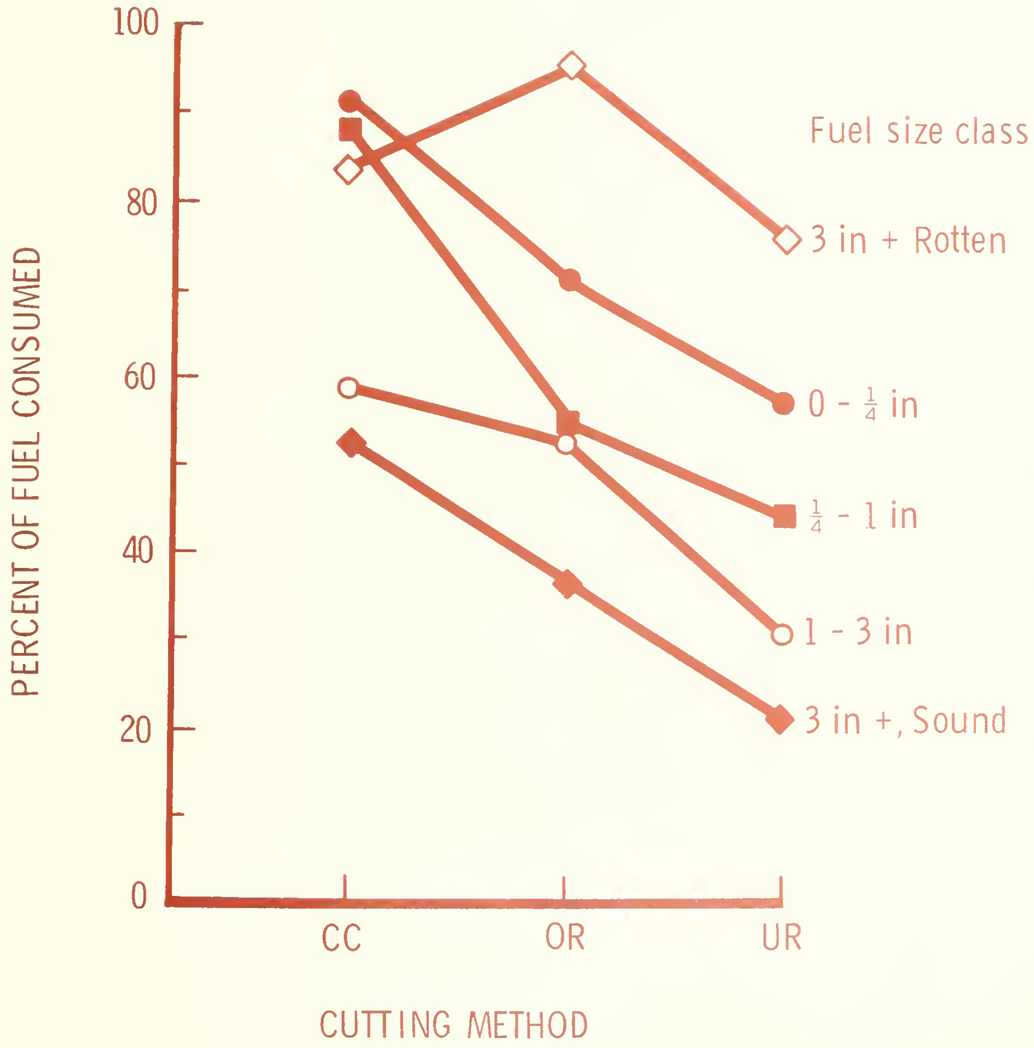

Figure 1.--Percent of fuels consumed in prescribed burning of clearcut, overstory removal, and understory removal cutting units.

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DAMAGE FROM LOGGING AND PRESCRIBED BURNING IN PARTIALLY CUT DOUGLAS-FIR STANDS

Robert E. Benson[1]

ABSTRACT

Damage from tractor logging and slash burning in a Douglas-fir stand on gentle terrain was measured for three different types of timber harvesting. Logging damage was light in the selection-cut and understory-removal cutting units. In the overstory-removal unit, about 11 percent of the leave trees were killed by logging. Little damage from burning was incurred in the selection-cut and understory-removal units, but in the overstory removal unit an additional 56 percent was killed by burning.

KEYWORDS: logging damage, prescribed burning, tree wound

Silvicultural needs and forest management objectives are sometimes best achieved by the partial cutting of timber stands. The success of partial harvesting depends in part on the extent of damage to residual or "leave" trees.

In a study begun recently at the Lubrecht Experimental Forest[2] east of Missoula, Mont., researchers are evaluating physical and biological effects of several harvesting methods and postharvest treatments. Objectives are to compare effect of harvesting techniques on populations of western spruce budworm (*Choristoneura occidentalis* Freeman) a common pest in the area, and to achieve more species diversity. This research note reports initial damage incurred to leave trees from logging operations and prescribed burning. Subsequent change from disease, insects, or wind may be assessed in future studies.

STAND CONDITIONS AND HARVESTING OPERATIONS

The study site is on a gently rolling area in a stand of primarily Douglas-fir (*Pseudotsuga menzeisii*), with some western larch (*Larix occidentalis*), ponderosa pine (*Pinus ponderosa*), and lodgepole pine (*Pinus contorta*) mixed in. The area had been cut over in the past, resulting in patches of large and small trees, with occasional two-storied stands of several ages. The area is primarily Douglas-fir/dwarf huckleberry habitat type (*Pseudotsuga menzeisii/Vaccinium caespitosum*), as classified by Pfister and others (1977).

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[1]Research forester stationed at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

[2]This is a cooperative study between the Intermountain Forest and Range Experiment Station and the University of Montana School of Forestry. Complete plans of all phases of study are on file at the Forestry Sciences Laboratory, Missoula, Mont., and the School of Forestry.

Four cutting units were included in the overall study. One unit was clearcut and only the three units that were partially cut are discussed here. One unit was selection cut to remove suppressed and defective trees and achieve desirable spacing for the remaining trees, following the guidelines of the Montana Department of Natural Resources, Division of Forestry. In the other units, the objectives were to interrupt the spruce budworm life cycle. On one unit the overstory was cut to remove larger trees where the budworm overwinters and from which larvae are dispersed. On another unit the understory was cut to remove smaller trees on which dispersed larvae light and begin feeding. Where possible, ponderosa pine, western larch, and lodgepole pine were retained to improve species diversity.

The specific treatments were:

Selection cutting - About half the sawtimber and pole-size stems were harvested. Residue was tractor-piled for burning.

Understory removal - Vigorous young sawtimber and a few poles were marked for leave. Defective and older sawtimber trees were cut and all trees under 5 inches d.b.h. were cut.

Overstory removal - All trees over 9 inches d.b.h. were cut, and all Douglas-fir over 5 inches d.b.h. were cut to meet the objectives stated above. Remaining stems were thinned.

Trees were felled and bucked conventionally using chainsaws and were yarded with a crawler tractor. Where residues were removed from the site, small stems were bundled prior to yarding. Merchantable stems were skidded whole-tree to the landing for limbing. Harvesting began in July 1977 and was completed October 1977. The logger was thoroughly briefed on study objectives. Research personnel were usually present to provide advice and to insure close adherence to logging and utilization specifications. The number of stems before and after logging are summarized in table 1.

Burning was done in late summer of 1978 after 1 year of curing. The overstory removal unit was burned under moderate-to-hot burning conditions and the fire was highly successful in reducing fuel volumes. The understory removal unit was burned under more moist conditions; fine fuels were consumed, but larger fuels were reduced only by about one-third (Steele in press).

Table 1.--*Number of live green trees per acre, pre- and postharvest, by diameter class for each cutting and residue treatment, Lubrecht Experimental Forest, 1977*

Cutting and residue treatment	Diameter class, live green trees									
	1.0-4.9 inches		5.0-8.9 inches		9.0+ inches		Total		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	Number per acre								*Number per hectare*	
Selection cut										
Residue piled and burned	319	46	134	48	87	54	540	148	1334	365
Overstory removal										
Residue left	354	141	83	73	55	7	492	221	1215	546
Residue burned	854	390	[2] 53	72	71	2	978	464	2516	1146
Residue removed	280	202	[2] 59	64	103	8	442	274	1092	677
Understory removal										
Residue left	800	0	138	38	49	25	987	63	2438	156
Residue burned	560	0	214	33	82	25	856	58	2114	143
Residue removed	220	0	42	19	104	45	366	64	904	158

[1]Green seedlings under 1 inch d.b.h. are not included because they are not involved in the damage analysis. Complete stand tables are on file at the Forestry Sciences Laboratory, Missoula, Mont.
[2]The apparent increase in trees per acre is due to preharvest sampling error.

Logging damage was evaluated by measuring and visually estimating scars and crown breakage n marked leave trees tallied on 1/10th-acre fixed plots. Evaluation was begun following log- ing, but in some units was not completed until the following summer. The assessment included rea and location of scars, and the number and stub-length of broken green branches. These njuries can influence the susceptibility of the tree to entrance of pathogens. No attempt was ade to detect presence or absence of pathogens at this time. By the summer following logging, ost scars were 80 to 90 percent covered with pitch, except for scars on small trees of low- igor, particularly in the overstory removal unit.

The damage to marked leave trees is summarized in table 2. Additional trees in the over- tory removal and selection units were not cut, but these were not included in the damage ssessment because there was no intent to protect them.

Table 2.--*Logging damage to leave trees in partial cutting units, Lubrecht Forest, 1977*

Cutting and residue treatment	Number marked leave trees		Logging damage[1]				
			None	Broken branch or top	Bole[2] scar	Stump[2] scar	Killed
	Per acre	*Per ha*	- - - - - - - - - - - *Percent*	- - - - -	- - - - -	- - - - -	- - - - -
Selection							
Residue piled and burned	64	158	81	6	4	8	<1
Overstory removal							
Residue left	82	202	67	8	12	7	6
Residue burned	96	237	53	10	11	15	11
Residue removed	68	167	69	5	9	11	6
Understory removal							
Residue left	63	155	99	0	1	0	0
Residue burned	58	143	88	6	3	3	0
Residue removed	64	158	89	1	2	8	0

[1]A few trees had two types of damage. Damage shown here is most serious damage incurred.
[2]Scars 1 foot or less above ground were called stump scars; over 1 foot above ground, bole scars.

Trees Killed or Missing

In the overstory removal unit, from 6 to 11 percent of the marked leave trees were killed r were missing. These were virtually all uprooted or flattened. The understory removal unit ıd no dead or missing leave trees, and in the selection cut less than 1 percent were killed.

Bole Damage

Damage to the stump (1 foot or less above ground) or bole of the tree (over 1 foot above round) was the most common injury in virtually all treatments (table 2). In general, the ıttern was as might be expected; small-size leave trees sustained more frequent damage. In ıe understory removal unit, from 1 to 10 percent of the leave trees had bole or stump scars, ıd in the selection cut 12 percent had scars, but in the overstory removal unit bole or stump car damage occurred on up to 26 percent of the leave trees.

The frequency of bole damage did not appear to be related to the type of residue treatment, ven though the "residue removed" treatment required yarding of more stems. One possible reason s that most of the residue was small stems, less likely to cause damage in felling and skidding ıan larger residues such as snags or large down material. There was very little large dead or ıll material on the site. Also, as mentioned earlier logging specifications were closely ıllowed.

Large scars that occur close to the ground usually have the greatest potential for infectio because of warmer and moister conditions. In all cutting units, half or more of the trees that were scarred had stump scars, and most of the bole scars were less than 2 feet above ground (table 3).

Table 3.--*Percentage of leave trees with stump or bole scars by height of scar above ground and size of scar, Lubrecht Experimental Forest, 1977*

Cutting method	Height of scar (ft)					
	<1	1-2	2-3	3-5	>5	Total
	Percentage of leave trees					
Selection cut	8.0	2.6	0.4	0.4	0.6	12.0
Overstory removal	11.2	4.7	2.5	1.9	1.6	21.9
Understory removal	3.7	1.9	0	0	0	5.6
	Size of scar (in^2)					
	1-10	11-30	31-50	51+	Total	
	Percentage of leave trees					
Selection cut	2.6	2.7	2.9	3.8	12.0	
Overstory removal	13.5	6.7	1.4	0.2	21.9	
Understory removal	2.1	2.5	0.8	0.2	5.6	

In the understory removal unit where only smaller trees remained, most of the scars were under 10 in^2 in size (table 3). In the understory removal unit where leave trees were larger, nearly half the damaged trees had scars 11 to 30 in^2 in size. In the selection unit nearly one-third of all the trees damaged had scars exceeding 50 in^2 in size. The larger scars in the selection cut were probably because slash was machine piled, which made large scars more likely but no attempt was made to determine whether the damage was from yarding logs or piling slash.

Broken branches and broken tops do not usually seriously damage young trees, provided the damage is not extensive on any one tree. Most leave trees had no crown damage or only a few broken live branches (table 2). Leave trees in the overstory removal unit had the most crown damage, but not substantially greater than in the selection and understory removal units.

Stub length can be a factor in disease entry because long stubs do not heal rapidly, thus allowing greater time for access of pathogens. Stub length on all trees with broken branches was as follows:

Stub length	Percentage
1 inch or less	77
2-4 inches	17
5 inches or more	6
	100

In general, crown damage was less common than damage to the bole as shown in table 2, even in the overstory removal treatment where residue was removed.

Tree Size and Logging Damage

Generally smaller trees seem more susceptible to logging damage than larger trees, althoug comparisons in this study are limited because size of marked leave trees differed among the three cutting units.

All of the leave trees killed in logging were 1.0 to 5 inches d.b.h., except in the overstory removal unit where a small number of 5-inch to 9-inch leave trees were killed. In addition, bole and stump damage in the overstory removal unit was more frequent on smaller trees:

Residue treatment	Leave trees with stump and bole scars	
	1.0-4.9 inches	5.0+ inches
	- - - - - - Percent - - - - - -	
Residue left	26.1	12.1
Residue burned	36.4	6.4
Residue removed	33.9	12.8

Trees 1-5 inches d.b.h. in the overstory removal unit also suffered crown damage more frequently than larger trees. Crown damage averaged 20 percent of the leave trees 1-5 inches, but only 11 percent of the larger trees had crown damage.

DAMAGE FROM PRESCRIBED BURNING OF RESIDUES

Logging residues in the understory and overstory removal units were broadcast burned in 1978 after one season of curing. Some minor arrangement of fuels were made to protect leave trees and provide uniform fuel conditions, but otherwise fuels were left from the logging operation. Damage from burning the overstory and understory removal units was evaluated in 1979. No appraisal was made in the selection cut because piling fuels virtually eliminated damage to leave trees.

In the understory removal unit, there was relatively little damage from burning, but in the overstory removal unit 67 percent of the marked leave trees were dead or missing following burning; only 10.6 percent had been killed in the logging operation, so over half the leave trees were apparently killed by the burning. Damage from burning is summarized in table 4.

Table 4.--*Damage from prescribed broadcast burning in overstory removal and understory removal units, Lubrecht Experimental Forest, 1978*

Item	Overstory removal unit (96 leave trees per acre)	Understory removal unit (58 leave trees per acre)
	- - - - - - - - Percent of leave trees - - - - - - - -	
Killed in logging	10.6	0
Killed by burn	56.3	4.8
Live with bole scorched	7.6	15.5
Live with crown scorched	11.9	8.3
No damage from burn	13.6	72.4
	100.0	100.0

Most of the trees killed by burning had both crown scorch and bole char or scorching. In the understory removal unit, bole scorch was more frequent than crown scorch. In the overstory removal unit, crown scorch was somewhat more common, but there were so few live trees remaining the type of damage probably has little significance.

The extent of crown scorch, bole scorch, and char was also estimated, but again, so few trees were damaged in the understory removal unit, and so few live trees remained in the overstory removal unit, detailed breakdown of damage was not warranted.

The overstory removal unit was burned under conditions that were somewhat "hotter" than desired; in addition, the leave trees that remained in this unit were of poor quality and low vigor. This was due partly to their position in the crown canopy, and also because of heavy past budworm defoliation. Many of the crowns were very sparse, with a high proportion of dead flammable material.

DISCUSSION

Logging damage to marked leave trees in the selection-cut unit and in the understory removal unit was minor, with virtually no trees being killed, and only light crown breakage or scarring of the main stem. In the overstory removal unit, one-third to one-half the leave trees had some damage, but it did not appear that logging damage alone would severely impair future stand development.

This assessment was based on first-year assessment of physical injury only, and the susceptibility of the leave trees to insect, disease, or weather-related damage will not be known for several years.

Prescribed burning did have a severe impact in the overstory removal unit. Over half the leave trees were killed, and there was fire damage in addition to the initial logging damage. The trees remaining in the overstory removal unit were generally of poor vigor, and several years will be needed before survival of the leave trees in the burned treatment can be compared with those in the units with residue removed or residue left in place.

Based on initial observations, all three types of cutting can be done with an acceptable level of damage, even where residues are removed. However, treating slash by burning in the overstory removal unit, where mostly small trees remained, destroyed or damaged most of the leave trees. Different fuel arrangement, different burning conditions, or both are apparently needed when broadcast burning in this type of situation.

In the understory-removal and selection-cut units, both logging damage and burning damage were minor. Because the number of leave trees and their size is similar in both cutting units, future stand development can be compared among the four residue treatments.

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EFFECT OF HEATING RATE ON CHAR YIELD FROM FOREST FUELS

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ABSTRACT

Char yield at 500° C has been measured for 40 typical forest fuels, including foliage, wood, small stems, and bark. The effect of changing heating rates was determined from 20° C/min to about 1000° C/min, to simulate a range of burning conditions. The average of all fuels was 26.7 percent char at 20° C/min, decreasing to 23.9 percent at the highest rate. Each of the fuel types gave a similar small decrease in char yield as heating rate increased. Relative char yields for individual fuels, which can be used to compare flaming or glowing combustion tendencies, are nearly independent of heating rate.

KEYWORDS: forest fuels, char yield, heating rate.

Mathematical models, which have been developed to predict fire behavior in forest fuels, recognize both flaming and glowing combustion mechanisms of heat release from the fuels (Rothermel 1972; Albini 1980). Flaming combustion requires volatile products released by heating the solid fuel. Glowing occurs in the solid carbonaceous product. Present models use the total heat of combustion as the heat source for spreading fire but do not separate the two mechanisms. Separating the heat of combustion of volatiles from that for char would allow a more detailed description of the fire, which could then be used in improved or new models. The amount of char formed depends in part on fuel chemistry (Rothermel 1976) and could provide a sensitive indicator of differences in fire behavior. High char yields, due to fuel chemistry or application of fire retardants, would limit fire spread to smoldering at the expense of flaming (Albini 1980). On the other hand, smoldering combustion can complicate fire behavior and is very difficult to suppress (Ohlemiller and others 1979).

Char fractions are easily measured by thermogravimetric analysis (TG). Commercial instruments provide rapid and precise analysis and can be applied to a wide variety of forest fuels. One problem with this method is that normal TG heating rates are far lower than rates expected in a fire. Therefore, the sensitivity of char formation to heating rate needs to be examined before TG measurements can be used in models of real fires.

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The fuel heating rate in a fire is highly variable, depending on the heat flux to the fuel, fuel particle size, and thermal diffusivity, among other factors. Even adjacent particles are likely to experience a range of heating rates. There seems to be little agreement on a representative heating rate for a "typical" fire. The ASTM E119 fire test for building material requires a surface heating rate of about 100° C/min to simulate building fires. McCarter (1972) used a 60° C/min rate to approach those in burning cellulose. Walker (1963) indicated surface heating rates of 250° to 500° C/min may be more representative of wildland fires. Thus, common TG rates of 5° to 20° C/min may be 10 to 100 times slower than those found in spreading fires. Although slower heating insures more accurate temperature measurements, the applicability to fire conditions needs to be verified.

Studies on cellulose (Broido and Nelson 1975), a component of forest fuels, showed a strong dependence of ultimate char yield on heating conditions. Rapid heating to 370° C resulted in about 12 percent char after 1 hour. In contrast, a 21-hour pretreatment at 275° C followed by heating to 370° C, produced more than 27 percent char. Extremely slow heating rates should also lead to increased char from cellulose. At very high heating rates (above 400° C/s) essentially all the cellulose can be converted to volatiles without char formation (Lewellen and others 1977).

The variations in char yield from cellulose have been attributed to competing reactions that favor charring at lower temperatures (Broido and Nelson 1975). Secondary charring of volatiles can also occur, depending on their residence time in the pyrolyzing cellulose matrix (Lewellen and others 1977). Similar variations due to heating rate have also been noted for wood pyrolysis (Lee and others 1977; Browne 1958). Variable char yield reported for forest fuels (Susott and others 1975) may have been due to the sensitivity of cellulosic components to heating rate.

The effect of heating rate on char yield from forest fuels components other than cellulose has not been determined, nor has charring of a wide range of fuels been studied. The objective of this study was to measure these effects for typical forest fuels. These fuel samples were available from a more extensive study of their thermal properties, which will be reported elsewhere.

EXPERIMENTAL METHODS

Samples.--The forest fuel samples used in this study are listed in table 1. Samples were selected to provide data on different parts of typical fuels found in wildland fires, including foliage, wood, small stems, and bark. Low-ash cellulose filter paper was included for comparison because considerable literature was available on its char formation.

In general, the green foliage and stem samples were frozen when collected and then freeze-dried to less than 10 percent moisture content. Wood, bark, and litter samples were air-dried at room temperature. All samples were ground to pass through a 20-mesh screen. Green samples were kept frozen prior to analysis.

Table 1.--*Forest fuel descriptions*

Number	Common name	Species	Part
1	Chamise	*Adenostoma fasciculatum* H. & A.	Foliage
2	Greenleaf manzanita	*Arctostaphylos glandulosa* Eastw.	Foliage
3	Big sagebrush	*Artemisia tridentata* Nutt.	Foliage
4	Gallberry	*Ilex glabra* (L.) Gray	Foliage
5	Utah juniper	*Juniperus osteosperma* (Torr.) Little	Foliage
6	Lodgepole pine	*Pinus contorta* Dougl.	Foliage
7	Pinyon pine	*Pinus edulis* Engelm.	Foliage
8	Slash pine	*Pinus elliotii* Engelm.	Foliage
9	Western white pine	*Pinus monticola* Dougl.	Foliage, dead
10	Ponderosa pine	*Pinus ponderosa* Laws.	Foliage
11	Ponderosa pine	*Pinus ponderosa* Laws.	Foliage, dead
12	Quaking aspen	*Populus tremuloides* Michx.	Foliage
13	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Foliage
14	Black oak	*Quercus velutina* Lam.	Foliage, dead
15	White fir	*Abies concolor* (Gord. & Glend.) Lindl.	Wood
16	White fir	*Abies concolor* (Gord. & Glend.) Lindl.	Wood, rotten
17	Grand fir	*Abies grandis* (Dougl.) Lindl.	Wood
18	Excelsior	*Populus* spp. L.	Wood, dead
19	Larch	*Larix occidentalis* Nutt.	Wood
20	Larch	*Larix occidentalis* Nutt.	Wood, lumber
21	Ponderosa pine	*Pinus ponderosa* Laws.	Wood
22	Ponderosa pine	*Pinus ponderosa* Laws.	Heartwood lumber
23	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Wood
24	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Wood, lumber
25	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Wood, rotten
26	Big sagebrush	*Artemisia tridentata* Nutt.	Stems
27	Utah juniper	*Juniperus osteosperma* (Torr.) Little	Stems
28	Pinyon pine	*Pinus edulis* Engelm.	Stems
29	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Twigs
30	Utah juniper	*Juniperus osteosperma* (Torr.) Little	Bark
31	Larch	*Larix occidentalis* Nutt.	Bark
32	Ponderosa pine	*Pinus ponderosa* Laws.	Bark
33	Douglas-fir	*Pseudotsuga menzeisii* (Mirb.) Franco	Bark
34	Cheatgrass	*Bromus tectorum* L.	Aerial plant, cured
35	Idaho fescue	*Festuca idahoensis* Elmer	Aerial plant, cured
36	Braken fern	*Pteridium aquilinum* (L.) Kuhn	Fronds, cured
37	Saw palmetto	*Serenoa repens* (Bartr.) Small	Fronds
38	Tundra, interior	*Hylocomium splendens* Hedw. and *Pleurozium schreberi* (Brid.) Mitt.	Top layer of black spruce understory
39	Duff	--	"F" layer, dead
40	Cellulose	--	--

Thermogravimetric analysis.--A Perkin-Elmer TGS-2[2] thermogravimetric system was used in all analyses. A Hewlett-Packard data acquisition system measured sample mass to 0.1 ug and run time to 0.04 second. All data were digitized and stored on magnetic tape for postrun calculations. Furnace temperature was programmed by the data system through a digital-to-analog converter which presented the TGS-2 furnace control with either a voltage ramp, for runs at a fixed rate, or a constant voltage for isothermal runs at 500° C. Two or more replicate subsamples of 5 ± 0.5 mg were charred under nitrogen flowing at 0.2 liters/min to a final temperature at 500° C. Three heating rate programs were used. In the first, samples were heated at a constant rate of 20° C/min from room temperature to 500° C. The second program was like the first up to 140° C but then the rate was increased to 200° C/min. In the third program, the sample was first heated to 140° C at 20° C/min to drive off moisture. The furnace was then lowered away from the sample and heated at a rate of 300° C/min to 500° C. While the furnace was in the lowered position, the sample temperature remained below 160° C. The inert sample atmosphere was maintained by a plug sealing the glass outer tube to the antistatic tube around the hangdown wire. After a 3 minute period for temperature stabilization, the preheated furnace was quickly raised to its normal position around the sample.

For the first program, described above, residues were weighed when the program reached 500° C. For the second, the furnace was held at 500° C for 30 seconds to insure temperature uniformity before the residue was measured. For the third program, residues were weighed 30 and 50 seconds after the furnace was raised. Residues determined by the first method were corrected for a 30-second hold at 500° C by assuming a constant weight loss rate at 500° C, equal to the rate from 498° to 500° C.

Ash content was determined after residue measurements by changing the sample atmosphere to air flowing at 200 ml/min. The furnace was then programmed at 20° C/min to 600° C to burn off all carbonaceous char. The resulting residues were grey to white, indicating complete ashing. The ash contents were used to correct sample weight at 140° C and the residues at 500° C to an ash-free basis. Moisture contents were also determined from TG analysis by using the weight at 140° C as the dry sample weight. The heating rates to 140° C were kept equal for each program in order to obtain comparable dry samples.

The TG system temperature was calibrated by the Curie point method (Norem and others 1970) using the alumel, nickel, and nicoseal Curie points at 163°, 354°, and 438° C, respectively. Heating programs were accurate to within 2° C. Sample temperature deviated considerably from the programs during highly endothermic or exothermic pyrolysis reactions, but these reactions were minimal when the final char residues were measured.

Several representative fuel samples, containing added Curie point standards, were pyrolyzed in the preheated furnace (third program) to estimate the heating rate. Samples reached the nicoseal Curie point at 438° C in about 15 seconds for an average heating rate of over 1000° C/min through most of the thermal reactions.

RESULTS AND DISCUSSION

Typical changes due to increased heating rate are shown in figure 1, which details the TG results for greenleaf manzanita foliage. The time derivatives of the TG curves (DTG) are shown to emphasize changes in pyrolysis rates and temperatures. Increasing the heating rate from 20° C/min (curve A) to 200° C/min (curve B) caused a nearly 10-fold increase in weight loss rates. Features present at 20° C/min shifted to considerably higher temperatures in the 200° C/min scan. The shift could not be accurately measured, however, due to the variable effects of reaction enthalpy and changing heat capacity during weight loss.

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Runs with the furnace preheated to 500° C (curve C) showed a further 10-fold increase in weight loss rate. These runs exhibited only one major weight loss peak, unlike runs with linear heating rates. This major reaction was essentially complete in 25 to 30 seconds for all samples studied. At the 200° C/min rate, the weight loss was also nearly completed after the 30 seconds hold at 500° C. The weight loss rates for runs at 20° C/min were typically less than 0.03 percent/s at the final temperature.

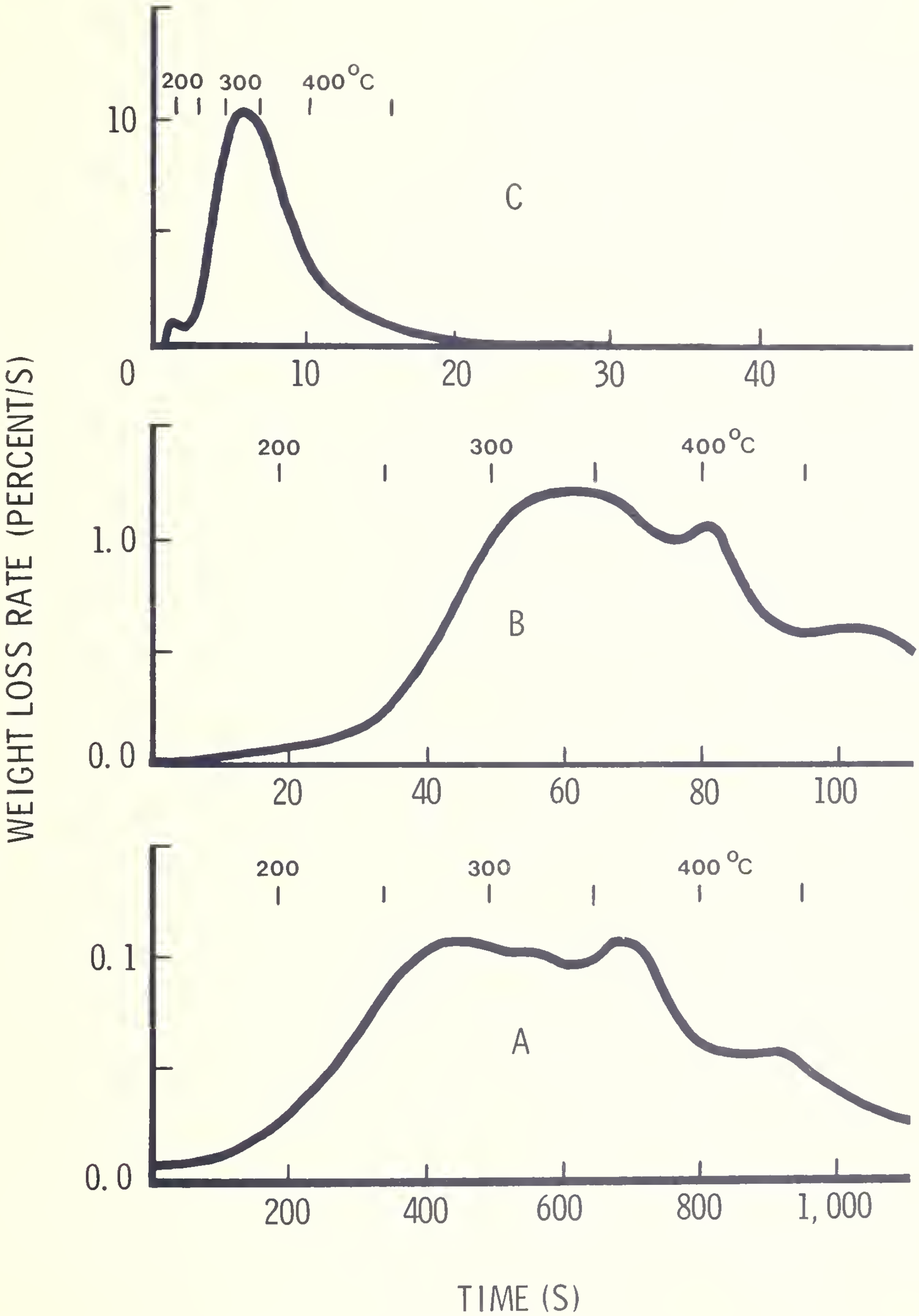

Figure 1.--Thermal analysis curves for greenleaf manzanita foliage at several heating rates: (A) 20° C/min; (B) 200° C/min; (C) sample placed in furnace preheated to 500° C. The approximate sample temperature were derived from TG curves for Curie point standards.

The curves in figure 1 show that pyrolysis was not complete, even at 500° C where weight continues to be lost. The weight loss rate was often one-third to one-half of the maximum rate, for runs made at the two linear heating rates. In spite of this, 500° C appears to be a reasonable temperature limit to generation of volatiles for flaming combustion because most of the pyrolysis is completed and the rate has slowed considerably. In a normal atmosphere this steadily decreasing weight loss rate would allow oxygen to diffuse to the char. Then glowing combustion would become the dominant mechanism for weight loss. In addition, because the char has reached a fairly stable condition, 500° C provides a convenient temperature at which the heating rate effects on char yield can be measured. Finally this temperature also provides a common point for comparisons between fuels.

Table 2 presents average char yields for different fuel parts (foliage, wood, stems, bark, and others) exposed to the three heating methods. Table 3 presents char data for individual fuels. The average standard deviation for all replicate runs was ± 0.25 percent. These data are on an ash-free, moisture-free basis, indicating only char formed from organic fuel. The average ash contents are also given in table 3. When the heating rate was increased from 20° to 200° C/min, the char yield decreased, but only by about 1 percent of dry fuel weight. A Student's t test showed that this decrease was not significant at the 0.05 probability level (2 to 3 degrees of freedom) for about 60 percent of the fuels. Thus, the effect of a 10-fold increase in heating rate on char yield was nearly negligible.

Table 2.--*Summary of the effect of heating rate on char yield from different fuel types*

Fuel type	Percent char[1] at 500° C			
			Preheated furnace	
	20° C/min	200° C/min	30 seconds	50 seconds
Foliage	27.4	26.4	25.7	24.5
Wood	22.0	21.0	19.5	18.8
Stems	25.3	24.8	23.4	22.5
Bark	36.5	34.6	34.4	33.3
Other	27.7	25.9	25.2	24.3
All[2]	26.7	25.7	24.8	23.9

[1]Ash-free, dry weight basis.
[2]Values are the average of all samples tested at the indicated heating rate.

Rapid sample heating with the preheated furnace resulted in less char than both the 20° and 200° C/min rates. The char values measured after 50 seconds should be most comparable to the other heating methods because each was allowed 30 seconds to pyrolyze at the final temperature. An initial 20 seconds was required to reach the final temperature in the preheated furnace. The average difference between char yields for the 20° C/min rate and 50 seconds in the preheated furnace was 2.8 percent. A decrease was significant at the 0.05 level for 95 percent of the fuels studied, confirming the trend seen at 200° C/min. Char yields after 30 seconds, which may be a better measure of the fuel available for glowing combustion, were also given in tables 2 and 3 for comparison.

Table 3.--*Char yield from forest fuels exposed to several heating rates*

Sample number[2]	Percent ash[3]	Percent char[1] at 500° C			
		20° C/min	200° C/min	Preheated furnace	
				30 seconds	50 seconds
		Foliage			
1	4.4	27.8	27.7	27.0	25.9
2	3.6	29.9	29.1	27.6	26.3
3	7.7	25.0	23.6	21.5	20.6
4	2.4	24.6	24.2	22.6	21.4
5	5.5	23.7	23.1	22.7	21.5
6	2.4	28.5	28.5	27.7	26.5
7	3.6	26.0	25.6	25.2	24.1
8	1.6	28.9	28.3	27.1	26.2
9	4.2	33.3	31.1	30.8	29.8
10	2.9	26.2	25.4	24.3	23.3
11	4.1	25.9	24.6	24.1	23.0
12	5.7	27.1	26.1	25.0	23.8
13	5.3	28.3	28.0	27.1	26.0
14	4.3	28.2	27.1	26.2	25.0
		Wood			
15	0.5	21.7	21.2	19.9	19.3
16	.2	20.9	20.0	19.1	18.3
17	.6	20.4	19.2	17.9	17.3
18	.4	15.2	14.0	12.9	12.4
19	.2	20.3	19.0	18.0	17.3
20	.2	23.2	21.5	20.5	19.7
21	.4	19.1	18.3	17.2	16.5
22	.3	19.9	19.3	18.2	17.4
23	.2	19.7	18.8	17.9	17.1
24	.2	21.7	20.8	20.0	19.2
25	.5	40.0	39.3	37.8	36.8
		Stems			
26	2.8	26.7	25.8	22.1	21.6
27	7.8	25.6	25.9	24.9	24.0
28	2.2	21.9	21.5	19.9	19.1
29	2.9	27.2	27.2	26.3	25.1
		Bark			
30	17.1	27.1	26.8	26.6	25.4
31	1.7	36.5	36.1	34.2	33.1
32	.8	46.2	43.9	43.7	42.6
33	1.6	36.3	34.8	33.5	32.2
		Other			
34	6.8	21.3	20.6	19.1	18.5
35	9.4	24.0	23.5	21.3	20.5
36	9.6	38.1	38.0	37.3	36.3
37	5.4	32.6	31.8	29.6	28.7
38	32.7	35.6	34.4	33.4	32.4
39	31.7	37.7	38.4	48.1	36.4
40	.1	4.9	4.2	4.1	3.8

[1]Ash-free, dry weight basis.
[2]Numbers refer to samples described in table 1.
[3]Average of ash percentages measured for all heating conditions.

The data in tables 2 and 3 show that char yield from typical forest fuels is only a weak function of heating rate above 20° C/min. Increasing the rate by a factor of 50 only decreased the average char by 2.8 percent, based on original organic fuel. All five fuel types showed essentially the same trend. Changes for wood samples, with high cellulose content, were not appreciably different from bark, foliage, or stems. Even for pure cellulose, the char yield only changed from 4.9 percent to 3.8 percent for the 20° C/min and preheated furnace method, respectively. Although prolonged heating of cellulose at low temperatures increases char yield (Broido and Nelson 1975), the effect was greatly reduced at the higher rates used in this study.

It is not clear which of the existing theories on char formation and the effect of heating rate would best explain the effect observed for these forest fuels. The secondary charring of volatiles, proposed by Lewellen and others (1977), can adequately explain the small effect of heating rate on charring of forest fuels. With this mechanism, char yield depends on residence time of volatile products within the pyrolyzing matrix. Residence times are reduced when the products are formed at the higher reaction temperatures resulting from higher heating rates. However, it seems unlikely that char can only be formed by secondary reactions of volatile products. The large char yields from most forest fuels, compared to cellulose (up to 46 percent for ponderosa pine bark), suggest that primary char forming reactions of some fuel components are also important. Additional studies at higher temperatures and higher heating rates would be needed to support this latter mechanism.

CONCLUSIONS

The data in table 3 show that heating rate is not a critical parameter in measuring relative char yields from forest fuels. If fuels are ranked in order of increasing char yield, and differences smaller than 1 percent are ignored, their order does not depend on heating rate. Comparisons obtained by thermogravimetric analysis at slower heating rates should be valid at the higher heating rates experienced in spreading fires. In addition, the TG experiments give other details of the volatile generation process which may be related to ignition or flammabilit characteristics of the fuels. Parameters such as weight loss rates and decomposition temperatures can be related to burning rates (Philpot and Mutch 1966) or to fire retardant effectiveness (George and Susott 1971).

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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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EFFECTS OF NITROGEN AND PHOSPHORUS FERTILIZER ON PLANTED PONDEROSA PINE IN WEST-CENTRAL IDAHO

Glenn L. Jacobsen, Richard A. Thompson, and
Russell A. Ryker[1]

ABSTRACT

Nitrogen and phosphorus fertilizers were applied to the soil surface in a 2-0 ponderosa pine plantation on the Payette National Forest in west-central Idaho. The study area was located in an Abies grandis/Acer glabrum *habitat type on a basalt soil. The fertilizer treatments did not increase survival or growth of the trees, nor did they increase the amount of competing vegetation. The only significant response was a reduction in survival caused by the high level nitrogen treatments.*

KEYWORDS: fertilization, *Pinus ponderosa*, plantation, nitrogen, phosphorus

In recent years, planted ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws.) has survived consistently well on the Payette National Forest, and most of the future improvement in pine plantations will come by increasing growth.

Increased growth of seedlings in the first three to five growing seasons would provide benefits in addition to increased wood production. It would shorten the time the trees are susceptible to damage by grazing livestock, thus shortening the time livestock must be excluded from a newly planted area. It would also improve esthetics by shortening the time between logging and the reappearance of trees.

---

[1]Respectively, silviculturist, Payette National Forest; soil scientist, Clearwater National Forest; and research silviculturist, Intermountain Forest and Range Experiment Station, located in Boise, Idaho.

Fertilization is one means of increasing tree growth. It is an accepted forest management practice in some areas of the United States where low levels of one or more mineral nutrients are responsible for slow tree growth. Although little fertilization has been done in the west-central Idaho area, we have observed numerous examples of increased tree growth from seedlings planted in or near burned slash piles. Increased growth may have been due to increased nutrients, increased moisture, lack of competition, or a combination of these items.

To find out if increased nutrients were responsible for increased growth, we began a fertilization trial in 1975 on the Payette National Forest in west-central Idaho. Only nitrogen (N) and phosphorus (P) were tested because they were the elements believed most likely to achieve a response on the planting site. We designed the study to determine the effects of N alone, P alone, and N and P combined on tree growth and on competing vegetation.

STUDY AREA

The study area was a clearcut unit on the New Meadows Ranger District, Payette National Forest. Slash was piled and burned and the site prepared in 1974. The unit was planted to 2-0 ponderosa pine seedlings in spring 1975. Plots were positioned midslope on a northeast aspect with a slope of about 25 percent. The habitat type was *Abies grandis/Acer glabrum.*[2] Elevation of the unit is 5,000 ft (1 500 m) above sea level.

The soils are developing from basalt materials of the Columbia River formation. They have ochric epipedons, cambic horizons, frigid soil temperature, and udic moisture regimes. They belong to the fine loamy mixed frigid family of Typic Dystrochrepts. Surface horizons are dark brown to very dark grayish brown silt loams with weak granular to coarse, weak subangular blocky structure; they are nonsticky and slightly acid. Subsoil horizons are dark yellowish brown, gravelly silt loams and silt loams; they are coarse weak to moderate subangular blocky structure, nonsticky, and medium to slightly acid. Soil depths average 45 inches (114 cm).

These soils represent soils commonly and widely found throughout the western Payette National Forest. Soil textures are favorable for good moisture-holding capacities, and parent materials supply "adequate" amounts of soil nutrients. Suspected natural state nutrient deficiencies are limited to nitrogen.

Soil compaction measurements with an air permeameter were conducted on an adjacent unit. Environmental and logging conditions are nearly identical. Average space was 19 percent near the surface and 16 percent for subsoils. Both values are above the minimum 15 percent guide, and no growth reductions were anticipated due to soil compaction.

No precipitation measurements were available for the site. The nearest precipitation information available was taken for a 15-year period from four gages located approximately 8 to 10 air miles to the north. Elevations of the gages varied from 4,173 to 5,510 ft (1 272 to 1 679 m) above sea level. Annual precipitation for the study area is about 38 inches (96 cm). Average precipitation for June is 2.41 inches (6.1 cm), July 0.67 inches (1.7 cm), and August 0.82 inches (2.1 cm).

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[2]Steele, Robert, R. D. Pfister, R. A. Ryker, and J. A. Kittams. 1975. Forest habitat types of Central Idaho. Review draft of a Research Paper, USDA Forest Service, Intermt. For. and Range Exp. Stn., 191 p.

METHODS

We auger-planted the 2-0 ponderosa pine seedlings on June 5, 1975, as part of the normal Ranger District reforestation program. The study was superimposed on the plantation. Plot dimensions varied in order to have 12 trees per plot.

We tested nine treatments in a randomized complete block design with five replications. The nine treatments were:

Control	No fertilizer
N_1	80 lb/acre of N
N_2	200 lb/acre of N
P_1	40 lb/acre of P
P_2	100 lb/acre of P
N_1P_1	80 lb N plus 40 lb P/acre
N_2P_1	200 lb N plus 40 lb P/acre
N_1P_2	80 lb N plus 100 lb P/acre
N_2P_2	200 lb N plus 100 lb P/acre

The lower levels were expected to be adequate to achieve a response on the soils of the study area. The higher levels were included to increase our confidence that enough fertilizer had been applied.

The fertilizers used were urea (46-0-0) and triple superphosphate (0-45-0). The fertilizer was broadcast on the plots October 7, 1975, during a light rainfall. Rain continued that evening so conditions were ideal for movement of the fertilizer into the soil.

Survival, total height, and diameter of the trees were measured in the fall of 1976, 1977, and 1978. An estimate of the percent coverage of competing vegetation was recorded for each plot at the time the treatments were applied and again in the fall of the next 2 years. The data were subjected to analyses of variance. When significant differences due to treatment were found, comparisons among means were made using a sequential method.[3]

RESULTS

No significant differences were found in third-year heights and diameters among trees receiving the different fertilizer treatments (table 1). The three treatments with the greater rate of nitrogen had an average third-year survival of 84 percent. The average survival for all the other treatments was 97 percent. Treatment N_2P_1 (83 percent) was significantly different from N_1P_1 (100 percent). Treatments N_2 and N_2P_2 just missed being significant at the 95 percent level, indicating that the heavy nitrogen applications had a real but detrimental effect on survival. Most of the mortality occurred the first year after treatment.

[3]Snedecor, George W. 1956. 534 p. Iowa State Coll. Press, Ames.

Table 1.--*Mean third-year survival, total height, and diameter of planted ponderosa pine trees*

Treatment	Survival	Total height[2]	Diameter[2]
	Percent	*Centimeters*	*Millimeters*
Control	97 ab[1]	52.2	15.3
N_1	98 ab	55.3	14.9
N_2	85 ab	51.2	14.2
P_1	92 ab	50.9	14.7
P_2	98 ab	48.2	13.8
N_1P_1	100 a	51.1	13.3
N_1P_2	95 ab	51.9	14.1
N_2P_1	83 b	54.2	15.9
N_2P_2	85 ab	56.5	13.1

[1]Values followed by the same letter are not significantly different at the 5 percent level (Snedecor 1956, p. 253).

[2]Analyses of variance tests revealed no significant differences between treatments.

Table 2 shows the mean percent coverage of mineral soil, shrub species, forb species, and grass and sedge species for the end of the 1975 growing season (just before treatment) and of 1976 and 1977. An analysis of variance was calculated for each year for all four categories. The analyses revealed significant differences in treatment effects on the shrubs only, and only in the second year, 1977. Plots treated with N_2P_2 had significantly less shrub coverage at the end of the 1977 growing season than plots receiving N_1, N_2, and N_2P_1 treatments. However, none of the fertilizer treatments had shrub coverages significantly different from the untreated plots.

The distribution of the competing vegetation was more closely related to position within the study area than to fertilizer treatments. Plots in blocks located on lower and midslope positions developed significantly higher coverage of grasses and sedges than upper slope plots. In contrast, forb species were more prevalent on upper slope plots. No significant differences existed in the distribution of shrubs and exposed mineral soil between blocks.

The results indicate that growth of planted ponderosa pine on *Abies grandis/Acer glabrum* habitat type in west-central Idaho cannot be increased by these fertilizer treatments. Even the competing vegetation was not increased. Why the lack of response is not known, but we think it is because adequate N was already available to meet ponderosa pine requirements. Moisture was not likely limiting since the soils have a udic moisture regime. The explanation of the increased growth associated with burned slash piles will require further research.

Table 2.--*Mean percent coverage measured in October 1975, 1976, and 1977*

Cover type	Year	Treatment								
		Control	N_1	N_2	P_1	P_2	N_1P_1	N_1P_2	N_2P_1	N_2P_2
Mineral soil	1975	63.3	66.9	64.4	67.5	68.5	68.7	66.1	63.7	77.9
	1976	26.5	20.5	17.2	22.9	24.7	23.6	20.0	21.2	33.4
	1977	12.0	10.7	7.1	13.7	15.4	13.0	9.0	8.8	16.0
Shrubs	1975	16.9	22.7	24.2	15.6	12.8	20.0	14.8	16.2	11.8
	1976	37.5	51.2	50.7	36.1	42.4	43.2	39.2	45.9	32.7
	1977	48.8 ab[1]	62.3 a	66.2 a	46.0 ab	51.7 ab	55.2 ab	51.6 ab	60.2 a	38.3 b
Forbs	1975	0.9	0.6	1.0	1.6	0.4	0.7	1.3	1.3	1.2
	1976	15.8	15.0	18.0	14.1	9.1	20.2	18.3	23.6	15.2
	1977	30.0	22.7	29.5	31.8	18.6	22.6	34.7	48.9	27.1
Graminoids	1975	0.4	1.1	1.0	0.7	0.6	1.8	0.6	1.2	0.8
	1976	3.1	4.7	4.5	6.1	9.5	7.8	3.0	6.9	8.2
	1977	7.7	7.6	11.6	15.7	13.4	15.0	7.4	16.1	12.2

[1]The values followed by the same letter are not significantly different at the 5 percent level (Snedecor 1956, p. 253).

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IDAHO NEVADA UTAH

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507-25th STREET, OGDEN, UTAH 84401

August 1980

EMERGENCE AND ATTACK BEHAVIOR OF THE MOUNTAIN PINE BEETLE IN LODGEPOLE PINE

Lynn A. Rasmussen[1]

ABSTRACT

Factors influencing the behavior of mountain pine beetles infesting lodgepole pine were studied during 1974 and 1975. More and larger beetles emerged from trees having thickest phloem, with the largest beetles usually emerging first. Beetles emerging in 1974 constructed more gallery and laid more eggs than did beetles emerging in 1975, probably due to the late beetle flight in 1975 and larger size of the females. Trees that were successfully mass attacked had lower inner bark temperatures than trees unsuccessfully attacked. The sex ratio of emerging beetles was 1.52:1, females to males; for attacking beetles it was about the same, 1.50:1, but for the boring beetles it was 2.34:1.

KEYWORDS: mountain pine beetle, temperature, behavior

The mountain pine beetle (*Dentroctonus ponderosae* Hopk.) is the most destructive insect nesting lodgepole pine (*Pinus contorta* Dougl.) forests throughout most of its range. Each er this bark beetle kills large numbers of trees over vast areas. Although beetle behavior a been the subject of many studies, much still remains to be learned. In an effort to better nerstand the mountain pine beetle, factors that influence and regulate its attack, and rgence behavior were studied in 1974 and 1975. Temperature is one of the most apparent nluences (see Safranyik [1978] for an excellent review of climatic effects on beetle biology); oever, aspect of attack, beetle size, and sex ratios also influence behavior.

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[1]Biological technician, Intermountain Forest and Range Experiment Station, Ogden, Utah. I work reported here was funded in part by the National Science Foundation and the Environ- ɛtal Protection Agency through a grant to the University of California. The findings and pinions expressed herein are those of the author and not necessarily of the sponsoring agencies.

METHODS

The study area was located in the Wasatch Mountains of northern Utah at an elevation of 2 248 m (7,600 ft). The area consists of a rather isolated stand of lodgepole pine of about 64.7 ha (160 acres), with an active, although somewhat static mountain pine beetle infestation. Data were recorded and beetles were collected daily throughout the length of the emergence and attack period, which lasted from July 24 to August 8, 1974, and July 30 to August 25, 1975. During each study year emerging beetles were caught in two 15.2 x 30.4 cm (6 x 12 inch) cages stapled to 20 trees infested the previous year. Twenty attacking beetles were collected at random from each of a total of 12 trees. Boring beetles were excised and collected at random from 10 galleries from each of 37 freshly attacked trees. Beetles were labeled, preserved in 70 percent alcohol, and taken to the laboratory where they were sexed according to the method described by Lyon (1958) and measured. In the fall, two 15.2 x 15.2 cm (6 x 6 inch bark samples from each of 20 trees were removed to determine brood (egg), attack, and gallery densities.

RESULTS AND DISCUSSION

Influence of Temperature on Emergence, Attacks, and Egg Laying

Beetle emergence and flight usually occur in late July and early August after a period of warm weather (Reid 1962a; Rasmussen 1974). In the study area, this is consistently the warmes period of the summer. Peak emergence dates for the years of this study occurred July 31, 1974 and August 17, 1975. The peak emergence date in 1975 was later than usual, probably because frequent storms and cool temperatures delayed larval development in the spring, and delayed adult emergence in late July and August.

In 1974, air and inner bark temperatures were measured at breast height when the initial attack on a tree was observed. The average air temperature at the time of initial attack for trees successfully mass attacked was 22.9° C (73° F). For trees unsuccessfully attacked the average air temperature was 23.1° C (74° F)--not significantly different. However, the averag inner bark temperatures were significantly different between successfully and unsuccessfully attacked trees (table 1).

Table 1.--*Comparison of average inner bark temperatures (centigrade), of seven successfully and four unsuccessfully attacked lodgepole pines*

	Successfully attacked			Unsuccessfully attacked				
Aspect	n	Average temperature	Temperature range	n	Average temperature	Temperature range	Difference in average temperature	t-test probabilit
North	7	23.5	21.5 - 25.0	4	25.9	25.5 - 26.0	2.4	<0.005
East	7	23.8	21.0 - 26.0	4	26.0	26.0 - 26.0	2.2	< .010
South	7	24.2	21.0 - 27.0	4	26.4	26.0 - 27.0	2.2	< .025
West	7	24.0	21.0 - 26.5	4	27.0	26.0 - 28.0	3.0	< .005

In addition, the initial attack on successfully attacked trees was either on the north or east aspect where the lowest inner bark temperatures occurred. Initial attacks on unsuccessfully attacked trees were not consistently related to any aspect. The reasons for these differences are unclear. Solar radiation heats the south and west aspects of trees to higher temperatures than north and east aspects (Powell 1967). Therefore, the higher temperatures recorded on unsuccessfully attacked trees may have deterred the beetles. It appears that higl inner bark temperatures of about 26° C (79° F) limit successful colonization of lodgepole pine by the mountain pine beetle.

North and east aspects of successfully colonized trees had the highest attack densities. Average attack densities per 30.4 x 30.4 cm (12 x 12 inch) for each aspect were: north = 10.0; east = 12.5; south = 8.4; and west = 7.1. The cooler inner bark temperatures of the north and east aspects seemed more conducive to beetle attack. Reid (1963) and Shepherd (1965) also observed highest attack densities on north aspects for mountain pine beetles infesting lodgepole pine in British Columbia and Alberta.

Prewinter (mid-October 1974 and early November 1975) samples of mountain pine beetle populations show that shorter galleries were constructed and fewer eggs were laid in 1975 than 1974, even though attack densities were nearly equal for the 2 years (table 2).

Table 2.--*Comparison of average mountain pine beetle attack, gallery and egg densities per 15.2 x 15.2 cm (6 x 6 inch) sample in 1974 and 1975*

Year	Peak emergence date	Average female length	Average attack density	Average gallery density	Average gallery/ attack	Average egg density	Average number eggs/cm gallery
		mm		*cm*	*cm*		
1974	July 31	5.1	2.4	73.2	31.1	90.5	1.2
1975	August 17	4.9	2.6	52.6	20.6	44.8	0.8

Because the beetles flew later in 1975 they had fewer days (before the onset of cold weather) to construct gallery and lay eggs. An adverse effect on the beetle population could occur when proportionately more eggs and fewer larvae enter winter because all eggs are killed by cold temperatures. In addition, the 1975 parent females were, on the average, smaller than in 1974; this also probably contributed to fewer eggs being laid that year. Reid (1962b) found large mountain pine beetles generally laid more eggs than did small beetles. McGhehey (1971) and Amman (1972a) in laboratory studies found that larger females generally laid more eggs per inch of gallery and that they also laid more eggs per day.

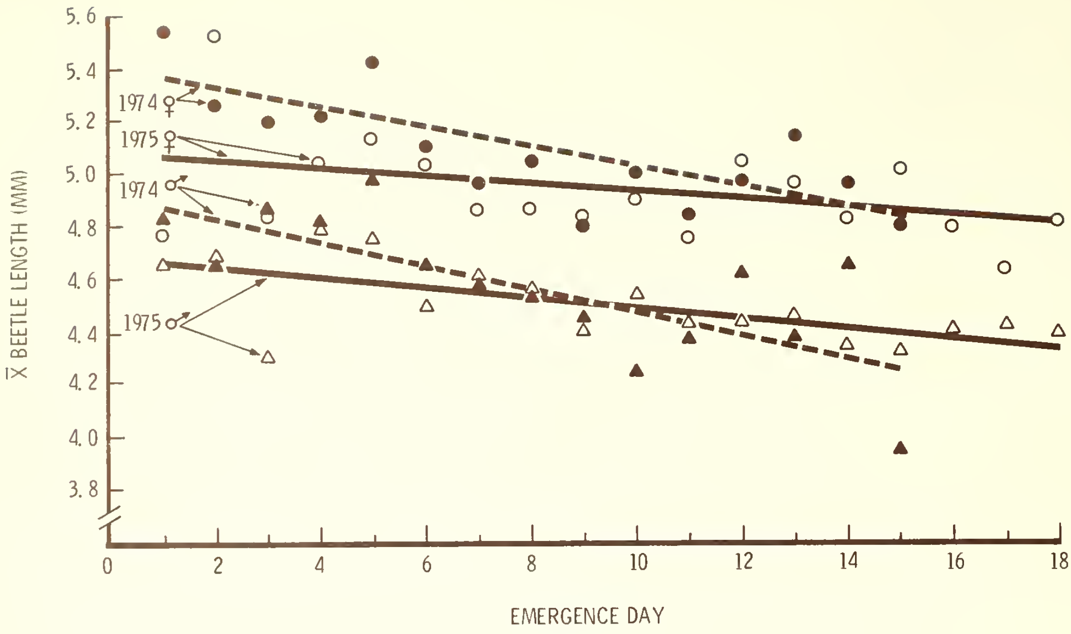
Beetle Size

The average sizes (beetle length) of both females and males that emerged early were generally larger than those that emerged later (fig. 1). Similar observations were made by Safranyik and Jahren (1970). In addition, both the number of emerging beetles and beetle size were directly related to phloem thickness, relationships noted by Amman (1972b) and Amman and Pace (1976) (table 3).

Both female and male beetle lengths appear to increase with an increase in phloem thickness. Differences between mean lengths in the thin and medium thickness groups, and between those of the medium and thick phloem thickness groups are significant at $P < 0.05$ for both sexes. Further, the variances about the means for both females and males are relatively small, ranging from only 6-11 percent of the means.

Sex Ratios

The sex ratio of the emerging, attacking, and boring beetles was determined for both years. The attacking beetles were those that had just landed on a tree or were walking about, making no attempt to bore in. The boring beetles were those actively engaged in gallery construction (table 4).



Females 1974: $\hat{Y} = (X)\text{-}0.0371 + 5.3821;\ r^2 = 0.59;\quad (P<0.005)$

1975: $\hat{Y} = (X)\text{-}0.0162 + 5.0790;\ r^2 = 0.20;\quad (P<0.100)$

Males 1974: $\hat{Y} = (X)\text{-}0.0448 + 4.9255;\ r^2 = 0.54;\quad (P<0.005)$

1975: $\hat{Y} = (X)\text{-}0.0193 + 4.6755;\ r^2 = 0.46;\quad (P<0.005)$

Figure 1.--Comparison of female and male mountain pine beetle size in relation to emergence da for 1974 and 1975.

Table 3.--*Comparison of the density and average size of emerging female and male mountain pin beetles per 30.4 x 30.4 cm (12 x 12 inch) cage*

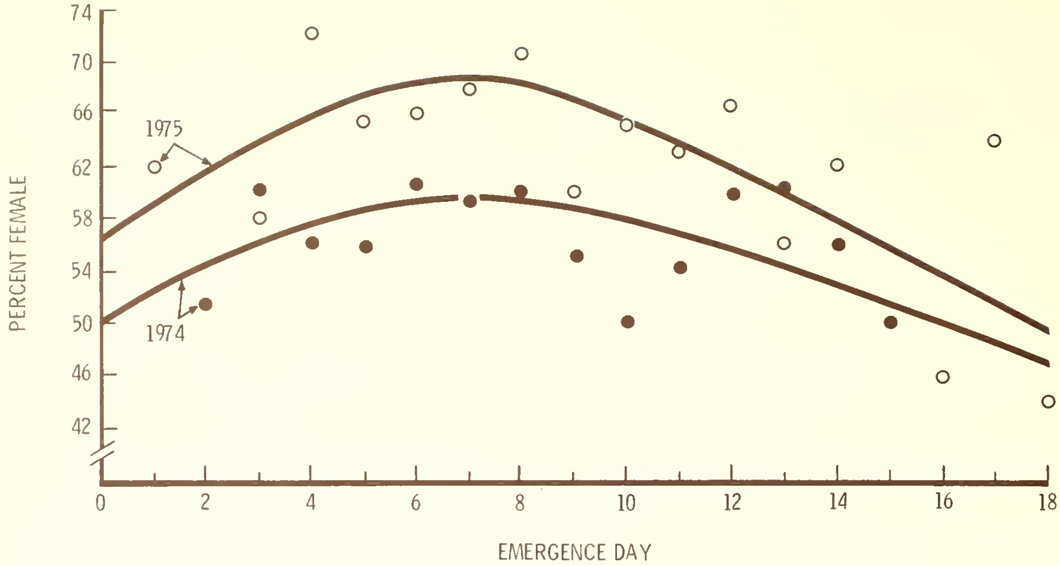
Phloem thickness	Females				Males			
	Total number	Average number per cage	Average size	Standard deviation	Total number	Average number per cage	Average size	Standard deviatio
mm			*mm*				*mm*	
1.1 - 1.6	142	14.2	4.77	0.364	82	8.2	4.36	0.326
1.7 - 2.1	161	10.1	4.87	.469	97	6.1	4.45	.372
2.2 - 3.2	281	20.1	5.01	.437	186	13.3	4.52	.375

Table 4.--*Sex ratios of the emerging, attacking, and boring mountain pine beetles*

Year	Emerging beetles		Attacking beetles		Boring beetles	
	Female:Male	Percent female	Female:Male	Percent female	Female:Male	Percent female
1974	1.48 : 1	59.7	1.58 : 1	61.3	2.11 : 1	67.8
1975	1.53 : 1	60.4	1.22 : 1	55.0	2.47 : 1	71.2
Both years	1.52 : 1	60.1	1.50 : 1	60.1	2.34 : 1	70.1

Sex ratios of the emerging and attacking beetles are similar; however, the sex ratio of the boring beetles favors the females a great deal more. The reason for this discrepancy probably is related to the polygamous nature of the males. Many leave galleries after mating and search for other unmated females. This could have resulted in a number of males being outside when galleries were opened for observation and in addition the number of males probably would be reduced during increased exposure to predation by clerid beetles and birds.

The percentage of emerging beetles that was female first increased and then decreased over the emergence time period. This difference was more pronounced in 1975 than in 1974 (Fig. 2). From curves fitted to the data, using the method of Jensen and Homeyer (1971), it was estimated that the percentage of females rose from about 50 percent to a maximum of about 5[illegible] percent, then declined to about 47 percent in 1974. A similar response was noted in 1975 when the percent female rose from 56 to 68 percent, then declined to 49 percent at the end of the emergence period. Although the correlation coefficient for 1974 data is low, it is evident that the same general trend exists in 1974 and 1975.



		Limits→	r^2	Pr.
1974:	$\hat{Y} = 59.3 - 0.375\,(7 - X)^{1.65}$	$0 \le X \le 7$	0.042	N.S.
	$\hat{Y} = 59.3 - 0.439\,(X - 7)^{1.4}$	$7 < X \le 18$		
1975:	$\hat{Y} = 68.4 - 0.480\,(7 - X)^{1.65}$	$0 \le X \le 7$	0.518	<0.005
	$\hat{Y} = 68.4 - 0.669\,(X - 7)^{1.4}$	$7 < X \le 18$		

Figure 2.--Percentage of the emerging mountain pine beetles that was female in relation to emergence day for 1974 and 1975.

CONCLUSIONS

The three most important results found in this study are:

1. Lodgepole pine trees successfully attacked by mountain pine beetles had significantl lower inner bark temperatures than trees unsuccessfully attacked.

2. Cooler inner bark temperatures on north and east aspects seemed more conducive to beetle attack where higher attack densities were found and where the initial attack occurred on successfully attacked trees.

3. Beetles emerged earlier, constructed more gallery, and laid more eggs in 1974 than i 1975, probably due to warmer, drier weather.

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AQUATIC MACROINVERTEBRATES WITHIN THE PHOSPHATE MINING AREA OF EASTERN IDAHO

William S. Platts[1] and Douglas A. Andrews[2]

ABSTRACT

The composition and diversity of benthic macroinvertebrates in the upper Blackfoot River drainage were recorded during the summer and fall of 1973, 1974, and 1976 to provide data for future assessment of mining impact. Basket samplers filled with natural substrate were placed at randomly selected stations. Analyses revealed the number of taxa, many of which were widely distributed, to be large (84). Mayflies of the genus Baetis *and the midge family, Chironomidae, were the dominant forms. Shannon-Weaver heterogeneity indices for all stations ranged from 2.6 to 4.3, with most stations having 3.1 or higher. The benthic taxa of the upper Blackfoot River and its tributaries compare favorably with those of several unpolluted streams of southeastern Idaho. Several stations had large standing crop changes, but the causes of these changes are unknown.*

KEYWORDS: benthos, macroinvertebrates, fish, water quality, species diversity, surface mining, phosphate

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INTRODUCTION

In 1977, 83 phosphate mining leases covered 43,370 acres (17 551 ha) of federal lands in southeastern Idaho. The U.S. Department of the Interior, Bureau of Land Management and the USDA Forest Service have pending applications for additional mining leases. Lease approvals will result in applications for permits to build roads, conveyor systems, railroads, powerlines, dump sites, and communication sites.

A majority of the mine leases and potential mining sites are located on or near tributary streams of the upper Blackfoot River. Previous open pit mining operations in the study area have caused sediment and petroleum pollutants to enter Angus Creek (Platts 1970), a Blackfoot River tributary. Since this polluting period, the mining corporation has better contained mine-caused pollutants.

If the leases pending are approved, prospecting and mining will disrupt headwater streams in the Blackfoot drainage. As an example, the area proposed for mining in the Angus Creek watershed is 315 acres (127.5 ha)--129 acres (52.2 ha) in mine pits, 85 acres (34.4 ha) in waste dumps, 89 acres (36.0 ha) in roads, and 12 acres (4.9 ha) of water control structures. Mining operations of this magnitude could have adverse influences on Angus Creek.

At present, the full impact of surface mining on the biota is difficult to detect or quantify because of financial and methodological limitations. Some streams have already been influenced by surface mining, but data to evaluate the environmental consequences are scarce. This report, along with reports on fish population dynamics, hydrochemistry, macroinvertebrate-fish population relationships, and aquatic structural conditions, will provide these data and furnish a basis for evaluating any future changes in the drainage. With the acceleration of surface phosphate mining throughout southeastern Idaho, sediment will eventually increase in the streams and throughout most of the upper Blackfoot system (USDA Forest Service 1976), probably with detrimental effects on aquatic life in the Blackfoot system (USDA Forest Service 1976).

The aquatic environment and biota of the Blackfoot River drainage, including macroinvertebrates, were investigated from 1970 through 1976 to provide information for future assessment of mining impact on the drainage. Other reports discuss the relationship of fishery,[3] stream geomorphology, riparian environments,[4] and hydrochemistry (Platts and Martin 1978) to environmental conditions.

STUDY AREA DESCRIPTION

The study area is located in Caribou County, Idaho (fig. 1). The study streams are in the Blackfoot River drainage, the major drainage in the Caribou National Forest. These streams drain watersheds encompassing past, present, and proposed phosphate mining sites. The proposed sites could continue to detrimentally affect the stream environments (Platts 1975).

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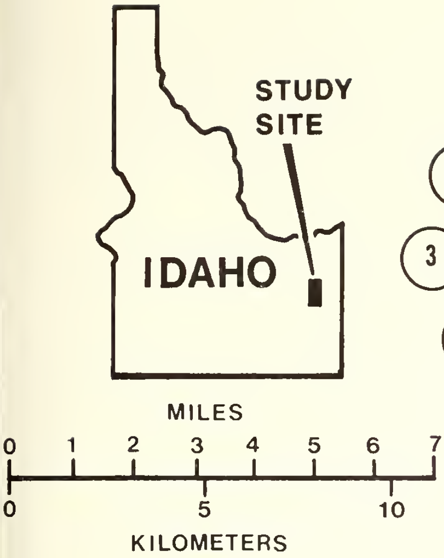

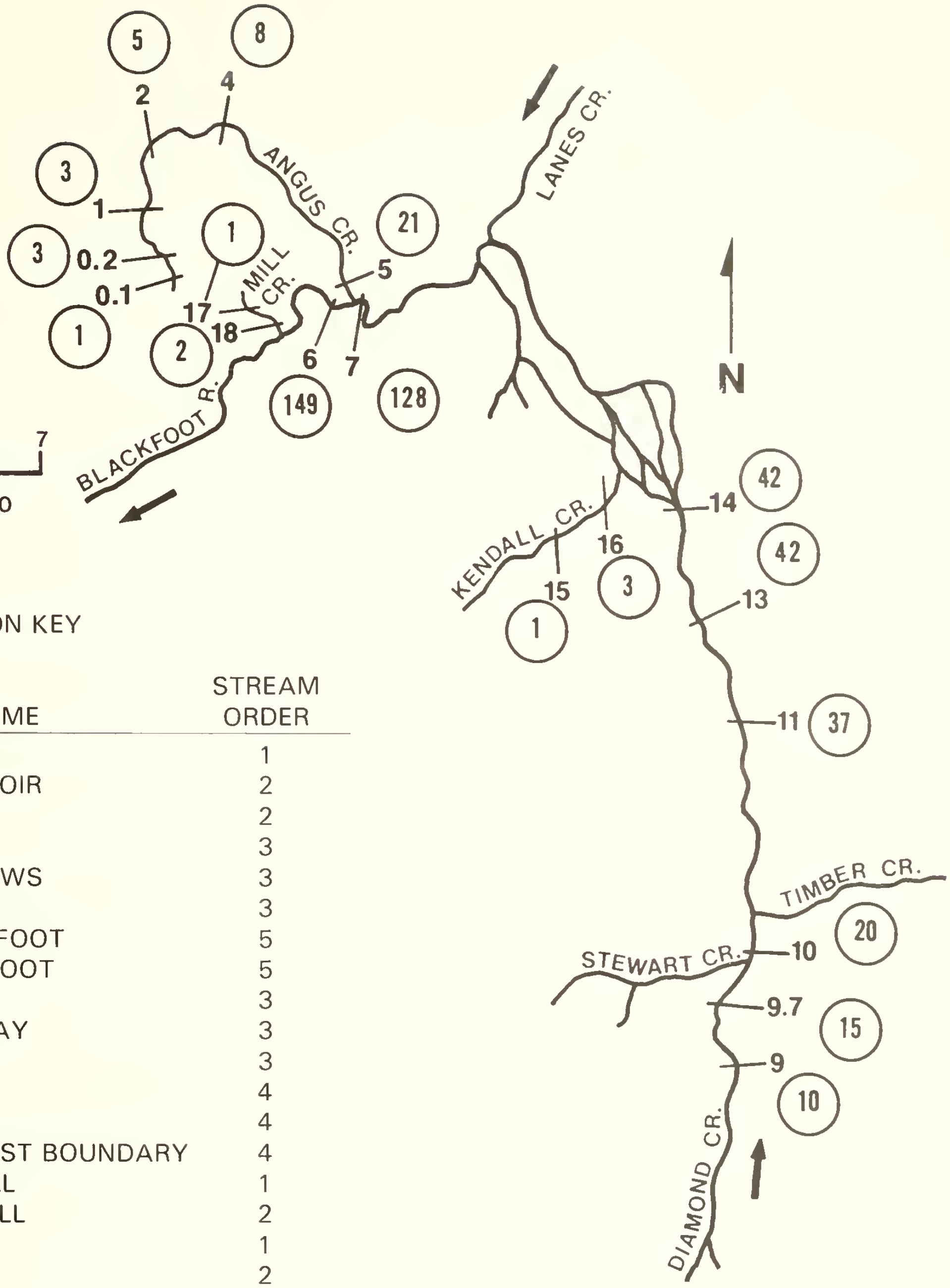

STATION KEY

SITE NUMBER	NAME	STREAM ORDER
0.1	SPRING	1
0.2	UPPER RESERVOIR	2
1	LONE TREE	2
2	CORNER HILL	3
4	BELOW NARROWS	3
5	LOWER ANGUS	3
6	LOWER BLACKFOOT	5
7	UPPER BLACKFOOT	5
9	DUGWAY	3
9.7	LOWER DUGWAY	3
10	STEWART	3
11	BEAR	4
13	CAMPBELL	4
14	CARIBOU FOREST BOUNDARY	4
15	UPPER KENDALL	1
16	LOWER KENDALL	2
17	UPPER MILL	1
18	LOWER MILL	2

Figure 1.--Study streams and locations of the benthic macroinvertebrate sampling stations. Stream orders and link numbers (n) of the stations are also given.

The location of the sampling stations on each stream; stream order, based on the classification of Leopold and others (1964); and the number of first order links[5] (Shreve 1966) above each station appear in figure 1.

Bedrock in the study unit is mainly Paleozoic and Mesozoic marine sediment composed of limestone, shale, sandstone, mudstone, and chert. The Phosphoria Formation is the principal source of phosphate mined in this region. These substrates, rich in nutrients and minerals, provide stream waters with the elements required for high aquatic biomass production.

The study streams are found mainly within the mountain valley bottomlands. The terrain is gently sloping. Streambanks often flood during spring and early summer and have a high vegetative productivity potential.

Mean annual precipitation varies from 20 to 30 inches (51 to 76 cm), mainly in the form of snow, and results in a mean annual runoff of 10 inches (25 cm). Hydrochemical data indicate the surface waters are very fertile and, when good physical habitat is present, large standing crops of fish can occur (Platts and Martin 1978).

Macroinvertebrate populations in the drainage may be affected by mining, logging, irrigation diversions, degraded irrigation return flows, and intensive streambank grazing by livestock.

STUDY STREAMS

Angus Creek

Angus Creek drains 13.9 mi^2 (36 km^2) of land ranging in elevation from 6,397 to 7,100 feet (1 950 to 2 165 m) and averaging 6,500 ft (1 980 m). Formed mostly in an alluvial valley, 92 percent of Angus Creek consists of low gradient channels in bottomlands; the remaining reach flows through a steep V-shaped canyon.

Although the base flow is mainly from springs, streamflow in Angus Creek changes radically because of snowmelt and in the headwaters because of stream diversions for mining purposes. Most of the streamside vegetation comprises grasses, willow, and sagebrush.

Angus Creek contains cutthroat trout (*Salmo clarki* Richardson), suckers (*Catostomus catostomus* Forester, *C. platyrhynchus* Cope), dace (*Richardsonius balteatus* Richardson), and sculpin (*Cottus* spp.). Angus Creek is an important spawning and rearing area for cutthroat trout (Thurow 1979). The fish population from station 4 upstream to within 800 yards (730 m) of the Angus Creek headwaters is dominated by cutthroat trout. The upper 800 yards (730 m) of water is barren of fish (1970-1976), except for a small, newly constructed reservoir where trout survival and growth have been excellent. In Angus Creek, from the narrows downstream to its mouth, the fish population is composed mainly of dace, redside shiner, and sculpin with lesser numbers of cutthroat trout.

[5]A link number is the number of first-order streams upstream from a particular sampling station. The link number indicates the topological complexity of the stream network above any given site.

Angus Creek has a mean alkalinity of 150 mg/liter, hardness of 142 mg/liter, temperature of 7°C, dissolved oxygen concentration of 12 mg/liter, and pH ranging around 7.5 (Platts and Martin 1978). Phosphorus concentrations are high. Mean values for dissolved phosphate (orthophosphate) (0.11 mg/liter) exceeded levels which result in high biotic production in aquatic systems (0.01 mg/liter, McKee and Wolf 1971). These values exceeded the concentration of 0.05 mg/liter total phosphorus recommended as the maximum level that should be allowed in streams flowing into lakes (Federal Water Pollution Control Administration 1968). The high Angus Creek values for orthophosphate may be a natural condition due to the geological nature of the drainage.

The moderate concentrations of nitrogen compounds present (nitrate-nitrogen averaged 0.21 mg/liter) may have been a limiting factor to game fish. The ammonia levels present were below those known to be toxic to aquatic life (2.5 mg/liter, McKee and Wolf 1971). The turbidity in Angus Creek during spring runoff (11 nephelometric turbidity units [ntu]) is slightly higher than the recommended 10 ntu (Federal Water Pollution Control Administration 1968). This may be due to the high amount of particulate matter in Angus Creek, which in turn is reflected in its high fertility.

Blackfoot River

The Blackfoot River above the reservoir contains cutthroat trout, rainbow trout (*Salmo gairdneri* Richardson), sucker, dace, redside shiner, sculpin, brook trout (*Salvelinus fontinalis* [Mitchell]), and possibly brown trout (*Salmo trutta* Linnaeus). Cutthroat trout (some of trophy size) also migrate from the Blackfoot Reservoir to spawn in the river and tributary streams.

Hydrochemical values for the Blackfoot River were similar to Angus Creek. The turbidity, chemical oxygen demand, total organic carbon, and nitrate were, however, significantly lower than in Angus Creek. This may be due to the dilution factor of the larger stream, as well as to less development in the Blackfoot River watershed above Angus Creek. Total orthophosphates are higher than recommended limits (Federal Water Pollution Control Adminstration 1968; McKee and Wolf 1971).

Diamond Creek

Diamond Creek joins Lane's Creek to form the Blackfoot River. At present, there is little mining activity in the Diamond Creek area, except for exploration for minerals in the Stewart Creek drainage. Several mines have been proposed and will be located in this drainage in years to come.

Diamond Creek contains cutthroat trout, brook trout, sculpin, and possibly dace, redside shiner, and sucker. This stream is the primary tributary of the Blackfoot River for spawning and rearing of cutthroat trout. Beaver dam the stream and cut streamside vegetation and cattle graze on riparian vegetation, altering the banks. Irrigation diversion and stream splitting near its mouth often cause portions of Diamond Creek to dry up during summer and fall.

Diamond Creek hydrochemistry, in most cases, is comparable to that of Angus Creek and that of the Blackfoot River. Values for mean annual hardness, suspended sediment, chemical oxygen demand, and Kjeldahl nitrogen were higher than in Angus Creek and the Blackfoot River, while total dissolved solids and conductivity were less. All values, when considered individually, were well within the range for a good salmonid habitat. With a high mean dissolved phosphate concentration (0.11 mg/liter) and moderate nitrate level (0.15 mg/liter), Diamond Creek has the potential of being a highly productive system.

Kendall Creek

Kendall Creek once drained into Diamond Creek, but has been diverted into Spring Creek. Kendall Creek is 3 miles (4.8 km) long and has an average channel gradient of 6 percent in the upper half, which results in poor fish habitat in this reach. Below the Caribou Forest boundary, Kendall Creek flows onto the Diamond Creek valley and the stream gradient becomes much lower. The stream provides little spawning habitat for cutthroat trout. Mining and livestock grazing have occurred within the Kendall Creek watershed, but upstream from the Caribou National Forest boundary these uses have been light and so have had little impact.

Chemical values for Kendall Creek were less in all instances than for the streams previously discussed. The average dissolved phosphate concentration being less (0.04 mg/liter) would probably result in less primary production in this stream. The Kendall Creek chemical environment is suitable for salmonids, although it may support a lower fish density than other streams in the study area.

Mill Creek

Mill Creek drains part of the Wooley Range and should be distinguished from the Mill Creek that drains part of Dry Ridge. Mill Creek of the Wooley Range empties directly into the Blackfoot River. The stream is small, only 1.2 miles (3.4 km) in length and, with its 12 percent channel gradient, has little fishery value. The average stream flow is only 3.3 cfs. Mill Creek sustains a minor trout fishery near its mouth. Chemically, its waters show no major differences from the other study streams. Turbidity and pH are slightly higher than other streams, but not high enough to classify them as being different. A large waste dump in the headwaters poses a continual pollution source.

METHODS

Most stations for benthic macroinvertebrate studies were randomly selected in riffle areas, located on aerial photographs, and marked on the ground with numbered metal stakes for identification. Two sample sites (stations 6 and 7) were subjectively selected on the Blackfoot River to determine influences from Angus Creek on the Blackfoot River.

Benthic collections were taken monthly from study sites in the upper Blackfoot River, Angus Creek, Kendall Creek, and Mill Creek during August, September, and November 1973 and October 1974. A third set of samples was taken from August through October of 1976 on Angus Creek, Blackfoot River, and on six sites on Diamond Creek. Basket sampler (fig. 2) were used at each station to provide a consistent sampling technique (Hilsenhoff 1969; Mason and others 1973). The 0.45 ft^2 (0.04 m^2) hardware cloth baskets (mesh size 0.50 inch [1.77 cm]) were filled with gravel (7 to 15 cm diameter) from the stream. Three baskets per station were placed in a line perpendicular to stream flow for a minimum of 30 days to allow invertebrate colonization.

Figure 2.--Basket sampler used to collect benthic invertebrates.

At the end of the colonization period, the baskets were lifted quickly from the stream bottom and placed in plastic bags. All invertebrates and detrital material were removed from the substrate by rinsing and brushing. The removed materials were concentrated by being strained through a 0.017-inch (0.43-cm) mesh screen. Anything that passed through the screen was discarded. The material was placed in labeled jars, preserved with 70 percent ethanol, and transported to the laboratory.

The samples were sorted to the lowest possible taxa, identified, and counted. In the case of large numbers of invertebrates, the samples were subsampled using the Waters (1969) system. Species diversity (heterogeneity) indices were based on the Shannon-Weaver information function (Shannon and Weaver 1964).

RESULTS

Benthic Distribution

A complete list of the 84 identifiable taxa of benthic invertebrates collected in the basket samplers during the study is presented in table 1. Seventy-four taxa were identified (genus and/or species). Species richness ranged from 18 at station 9.7 (Diamond Creek) to 68 at station 5 (Angus Creek). Angus Creek had a total of 82 taxa followed by the Blackfoot River with 72 taxa. All the stations on Diamond Creek had a low number of taxa (18 to 29). This probably is partially due to the fact that only 1 year (1976) of sampling was done instead of 2 or 3 years of sampling as in the other streams.

Among the major groups genera were evenly distributed at all 18 sample stations. The lack of Mollusca in the basket samplers from Diamond Creek was an exception. Extensive qualitative sampling located only one specimen (*Lymnaea* sp.) of this phylum in Diamond Creek.

Table 1 also lists the five most abundant organisms taken at each station. Of a possible 33 sets of samples, the Ephemeroptera genus *Baetis* was the most abundant taxon on 28 occasions. Another mayfly, *Ephemerella inermis* was also abundant being found in 12 sets. The most abundant stonefly, *Nemoura* (Plecoptera), was found in 16 sample sets. The midge family, Chironomidae, was found in 31 of the 33 sample sets. The others taxa of major abundance were *Simulium* (11), *Turbellaria* (10), *Optioservus* (8), *Limnephilus* (7), *Hydracarina* (7), and *Gammarus lacustris* (6).

Only six genera (*Alloperia*, *Baetis*, *Cinygmula*, *Ephemerella*, *Nemoura*, and *Simulium*) were found at all 18 stations. Well over half of the taxa (48) were collected at nine or more of the sample sites and had widespread distribution in the upper Blackfoot River basin.

In several instances an organism figured prominently at one station but not at another. *Alloperia* in Diamond Creek, *Capnia* in Angus Creek, and *Baetis* in Mill Creek are examples. Thus, while 80 percent or more of the organisms consisted of 21 taxa at all stations, the kinds of organisms varied markedly between stations and within streams

Benthic Composition

The relative abundance of each major taxon from the 1976 samples is listed in table 2. No particular group consistently made up more than 10 percent of the number at any station. At nine stations, a single group, Ephemeroptera, nevertheless made up more than 40 percent of the community. Relative abundance of major taxa varied enormous among stations as would be expected from the scattered distributions of many of the invertebrates and from the varied taxa ranked among the five most abundant. Within specific streams most of the major taxa at each station were strikingly close in relativ abundance. Angus Creek was an exception with the Amphipoda and Oligochaeta being abundant at stations 0.2 and 1. These species probably reflect the occurrence of a small in-stream reservoir immediately upstream.

Table 1.--*Macroinvertebrates collected in the Blackfoot River drainage. The five most abundant organisms for each year are identified with an (*)*

STREAM	Mill Creek				Kendall Creek				Diamond Creek						Blackfoot River						Angus Creek												
STATION NO.	18		17		16		15		14	13	11	10	9.7	9	7			6			5			4			2	1		0.2	0.1		
SAMPLE YEAR	74	73	74	73	74	73	74	73	76	76	76	76	76	76	76	74	73	76	74	73	76	74	73	76	74	73	76	74	73	76	76	74	73
EPHEMEROPTERA																																	
Ameletus sp.	X		X		X	X		X	X			X	X	X		X			X		X	X		X	X	X	X	X	X		X	X	
Baetis sp.	X	X	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	X	*	*	*	*	*	*	*	*	*	X	*	X	X
Cinygmula sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	*	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		
Ephemerella aurivilli										X								X															
E. coloradensis	X		X		X	X	X	X	X	X	X	X			X			X			X	X		X	X			X			X		
E. doddsi	X		X	X	X	X		X			X							X				X						X					
E. grandis	X					X	X	X	X	X	X	X	X	X	*	X	X	*	X	X	X	X	X	*	X	X	X	X	X		X	X	X
E. inermis	X	X	X	X		X	X	X	X	*	X	X	X	*	*	*	*	*	*	*	*	*	*	X	X		X	X	X	X	X		
E. hecuba																			X														
E. tibialis									*	X	*	X	X	X				X															
Heptagenia sp.	X	X		X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X	X		X			X		X		X
Leptophlebia sp.																X			X		X		X	X			X						
Paraleptophlebia sp.	X	X	X	X	X	X	X							X	X	X	X	X	X	X	*	X	X	*	X	X	X	X	X	X	X	X	
Rithrogena sp.					X				*	*	X	X	*	X	X	X	X	X	X	X	X	X	X	X	X								
Tricorythodes minutus																	X		X	X	X	X	X										
HEMIPTERA																																	
Corixidae																	X					X								X			
Gerris sp.																																	
PLECOPTERA																																	
Allopera sp.	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	*	*	*	X	X	X	X		X
Brachyptera sp.	X	X	X	X	X							X		X					X		X	X					X			X			
Capnia sp.	X	X		X		X	X	X				X		X		X	X			X		X	X	X	X	*	X	X	X	X			
Hesperoperla pacifica	X	X	X		X		X		X	X	X		X	X	X	X	X	X	X	X		X	X	X								X	
Isogenoides sp.					X	X	X	X	X	X	X	X	X	X	X			X	X		X	X		X			X	X	X		X	X	
Isoperla sp.		X	X				X	X			X	X	X	X	X	X	X	X	X	X	X		X				X	X	X			X	X
Megarcys signata	X		X		X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	
Nemoura sp.	*	*	*	*	X	X	X	X	*	X	X	*	X	X	X	X	X	X	X		X	X	X	*	*	*	*	*	*	*	*	*	*
Paraleuctra sp.	X	X	X									X														X							
Pteronarcella badia		X	X	X													X		X					X									
Pteronarcys californica				X		X									X	X	X	X	X	X	X	X	X										
Skwala parallela	X		X		X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X	X			X	*	X	
TRICHOPTERA																																	
Athripsodes sp.	X	X		X												X	X		X	X	X	X	X	X	X	X	X	X	X		X		X
Brachycentrus sp.					X						X				X	X	X	X	X	X	X	X	X										
Cheumatopsyche sp.			X			X		X				X			X	X	X	X	X	X	X	X	X	X	X				X	X	X		
Ecclisomyia sp.	X	X	X	X	X	X	X	X													X	X		X	X	X	X	X		X	X	X	X
Glossosoma sp.				X		X										X	X			X		X											X
Helicopsyche borealis																X	X	X	X	X	X	X	X	X					X				
Hesperophylax sp.		X							X	X	X	X	X	X			X				X	X				X	X	X		X	X	X	X
Hydroptilidae			X	X	X	X	X								X	X	X	X	X	X		X	X		X	X		X	X				
Hydropsyche sp.	X		X			X	X			X					X	X	X	X	X	X	*	*	*	X		X	X	X	X	X		X	
Lepidostoma sp.	X			X											X	X	X	X		X	X			X			X			X	X		
Limnephilus sp.	X		X		*	*	*	*	X		X	X			X	X			X		X	X		X	X	X	X	X	X	*	*	*	
Neothremma sp.			X		*	X	*	*									X			X		X					X			X			
Oligophlebodes sp.			X		X	X	X	X																X									
Radema sp.	X		X		*	*			X			X												X	X	X	X	X		X	X		
Rhyacophila sp.	X	X	X	X	X	X	X	X	X	X	X		X				X			X				X	X	X	X	X	X		X		X
Triaenodes sp.															X	X		X			X			X							X		
Wormaldia sp.			X	X												X		X	X		X	X	X	X	X	X		X					

Table 1. (Continued)

Mill Creek				Kendall Creek				Diamond Creek						Blackfoot River						Angus Creek													STREAM
18		17		16		15		14	13	11	10	9.7	9	7			6			5			4			2	1		0.2	0.1			STATION NO.
74	73	74	73	74	73	74	73	76	76	76	76	76	76	76	74	73	76	74	73	76	74	73	76	74	73	76	74	73	76	76	74	73	SAMPLE YEAR
*	*	*	*	*	*	x	x				x			x			x	x	x			x	*	x	x	*	*	*		x	x	x	TURBELLARIA
																																	MOLLUSCA
x	x	x	x	x		x									x			x		x	x	x											*Ferrissia* sp.
x	x	x	x	x	x	x	x							x	x	x	x	x	x	x	x												*Fluminicola* sp.
x						x													x		x	x					x				x	x	*Gyraulus* sp.
x				x		x									x	x		x	x		x	x		x			x				x	x	*Lymnaea* sp.
x	x		x	x		x										x		x	x	x	*	*	x	x	x	x	x	x	x	x	x	x	*Physa* sp.
x	x	x		x	x	x									x		x	x		x	x	x	x	x		x	x	x	x	x	x	x	*Pisidium* sp.
																																	OLIGOCHAETA
	x		x	x	x	x					x	x			x					x	x		x					x	x		x		Lumbriculidae
x		x		x		x					x	x				x	x	x	x		x	x	x	x	x	x	x	x	*	x	x	x	Tubificidae
																																	HIRUDINEA
x				x		x									x					x	x	x	x	x		x	x	x	x		x		*Glossiphonia* sp.
																																	ACARI
*	*	x	x	x	x	x	x	x	x	x	x		x	x	*	*	x	*	*	x	x	x	x	x	x	x	x	x	x	x	*	x	Hydracarina
																																	AMPHIPODA
					x	*	*								x	x			x		x				x	x	*	*	*	x	*	x	*Gammarus lacustris*
															x	x				x		x	x			x			x	x			*Hyalella azteca*
																																	MEGALOPTERA
					x																x											x	*Sialis* sp.
																																	COLEOPTERA
						x			x					x			x			x	x		x		x	x	x		x	x	x	x	*Agabus* sp.
		x	x			x			x	x	x		x	x			x			x	x	x	x			x	x		x	x	x	x	*Ametor scabrosus*
								x							x			x			x	x	x	x		x	x	x					*Erychius* sp.
x	x	x	x	x	x	x								x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x		*Cleptelmis* sp.
x																					x			x									*Dubiraphia* sp.
							x								x	x			x	x	x	x			x		x	x					*Haliplus* sp.
x		x	x	x	x	x		x							x	x		x			x		x	x	x		x						*Heterlimnius corpolentus*
x		x	x															x			x	x	x	x			x						*Hydraena* sp.
*	*	*	*	x	x	x	x		x	x				x	*	*	x	*	*	x	x	x	x	x	x	x	x	x	x	x	x	x	*Optioservus* sp.
		x													x	x								x			x						*Zaitzevia parvula*
																																	DIPTERA
		x			x									x	x	x	x	x	x		x		x	x	x				x				*Antocha* sp.
		x	x		x					x					x	x		x	x	x	x	x		x				x		x	x	x	*Atherix variegata*
x	x	x	x				x								x				x	x		x	x	x	x	x		x	x	x	x	x	Ceratopogonidae
*	*	*	*	x	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	x	*	*	*	*	*	*	*	*	*	Chironomidae
	x	x																					x		x	x	x	x	x	x	x	x	*Dixa* sp.
	x		x	x	x	x	x		x							x	x		x	x	x	x			x							x	Empididae
																			x													x	Ephydridae
		x									x												x				x		x	x		x	*Hexatoma* sp.
x						x	x				x									x	x	x	x			x	x	x	x	x	x	x	*Limnophora* sp.
								x							x								x					x	x		x		*Liriopa* sp.
			x		x																	x			x		x	x			x		*Pedicia* sp.
x	x	x	x	x	x	x	x															x	x	x	x	x	x	x	x	x	x		*Pericoma* sp.
x	x	x	x	x	x	x	x	x	*	*	*	*	x	*	x	x	*	x	x	x	x	x	x	*	*	x	x	x	x	*	*	*	*Simulium* sp.
x	x	x	x	x	x		x																x	x		x	x	x	x	x	x	x	Stratiomyiidae
	x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x	x	*Tipula* sp.
49		54		54		50		25	24	23	29	18	21	56			58			68			67			43	57		42	55			TOTALS
65				61				46						72						82													STREAM TOTAL

Table 2.--*Percentage composition of the various benthic macroinvertebrate taxa distributed by station. Values are based on data from the summer and fall sampling series of 1976 unless otherwise identified. Values have been adjusted to the nearest 1 percent*

Taxon	Stream and stations: Diamond Creek						Kendall Creek		Angus Creek						Mill Creek		Blackfoot River	
	9	9.7	10	11	13	14	[1]15	[1]16	0.1	0.2	[1]1	2	4	5	[1]17	[1]18	7	6
Coleoptera	1	-	-	-	1	2	3	2	1	7	6	2	4	3	6	16	2	2
Diptera	15	22	43	12	40	30	16	6	61	13	17	50	6	37	13	15	25	25
Ephemeroptera	53	70	44	74	46	56	20	29	5	5	14	8	43	30	25	12	62	59
Mollusca	-	-	-	-	-	-	1	1	1	5	3	3	2	2	<1	<1	1	2
Plecoptera	27	6	9	10	10	9	5	7	23	8	18	10	18	2	25	27	6	7
Trichoptera	3	1	2	3	2	3	32	19	4	10	5	8	15	21	7	7	3	3
Turbellaria	-	-	<1	-	-	-	6	28	1	-	7	15	9	-	18	16	-	-
Miscellaneous[2]	<1	<1	2	1	<1	<1	17	8	4	[3]52	[4]30	4	3	5	6	7	1	99

[1]Based on 1974 samples.
[2]Acari, Amphipoda, Oligochaeta, Megaloptera, and Hemiptera.
[3]Mainly Oligochaeta.
[4]Mainly Amphipoda.

Benthic Standing Crops

As a stream flows through its drainage basin it usually increases in size. Up to a point, habitats and niches within the drainage system also increase. The link numbers (the numbers of the first order streams occurring upstream of each station) reflect an increase in drainage area and indicate the relative amount of tributary influence. These increases are reflected in higher standing crops of many species of aquatic animals and plants unless negative environmental stresses occur. The standing crop estimates based on the 1976 collections (fig. 3) show an increase in the downstream direction, with the exception of station 2 on Angus Creek, which had the lowest number of benthic animals at 4,100/m^2. This decrease is probably due to the stream environment at station 2. Angus Creek changed from a riffle habitat at the beginning of the study to a pond environment when beaver dammed the stream.

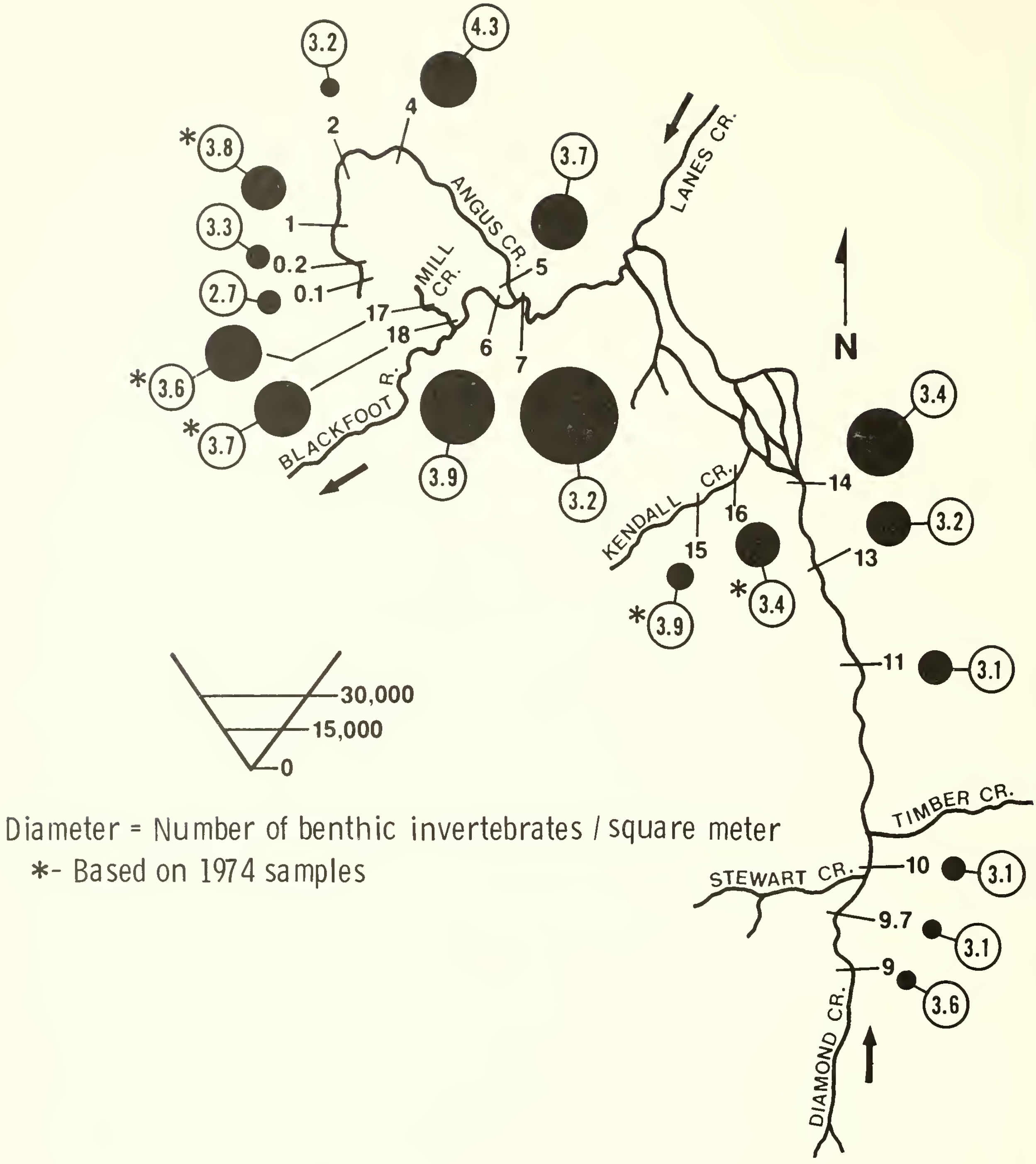

Figure 3.--Benthic macroinvertebrate standing crops and heterogeneity indices for fall samples, 1976.

Stations 6 and 7 on the Blackfoot River have the highest link numbers, 149 and 128, and reflect these in their size and large standing crops (table 3). There were, however, major decreases in benthic populations over time and in the number of taxa at stations 5, 6, and 7 near the mouth of Angus Creek (fig. 4). From 1973 to 1976, the benthic populations at station 7 on the Blackfoot River just above Angus Creek decreased from over 106,000/m^2 benthic invertebrates to fewer than 30,000/m^2. Stations 5 and 6 had similar decreases. The cause of these declines is unknown.

Table 3.--*Heterogeneity indices and standing crops of the benthic macrovertebrates of the upper Blackfoot River drainage. Blanks mean that no sample was collected*

Station		Heterogeneity indices			Number of taxa in analysis			Number/m^2		
		1973	1974	1976	1973	1974	1976	1973	1974	1976
Angus	0.1	2.7	3.3	2.7	36	40	40	8,475	9,211	7,683
Creek	0.2			3.3			42	--	--	4,946
	1	3.2	3.8		44	49		15,896	18,172	--
	2			3.2			45	--	--	4,106
	4	2.8	3.1	4.3	41	44	58	13,717	14,787	15,425
	5	3.6	4.1	3.7	50	64	52	30,585	21,480	15,906
Blackfoot	6	2.6	4.0	3.2	46	51	36	63,297	29,591	22,474
River	7	2.6	3.7	3.5	46	50	40	106,244	41,402	29,780
Diamond	9			3.6			21			4,356
Creek	9.7			3.1			18			4,608
	10			3.1			29			5,097
	11			3.1			23			7,259
	13			3.2			22			9,079
	14			3.4			26			13,598
Kendall	15	2.9	3.9		35	38		18,620	6,527	
Creek	16	3.3	3.4		42	40		15,280	11,906	
Mill	17	3.6	3.6		38	49		24,337	18,684	
Creek	18	3.6	3.7		36	40		12,969	17,100	

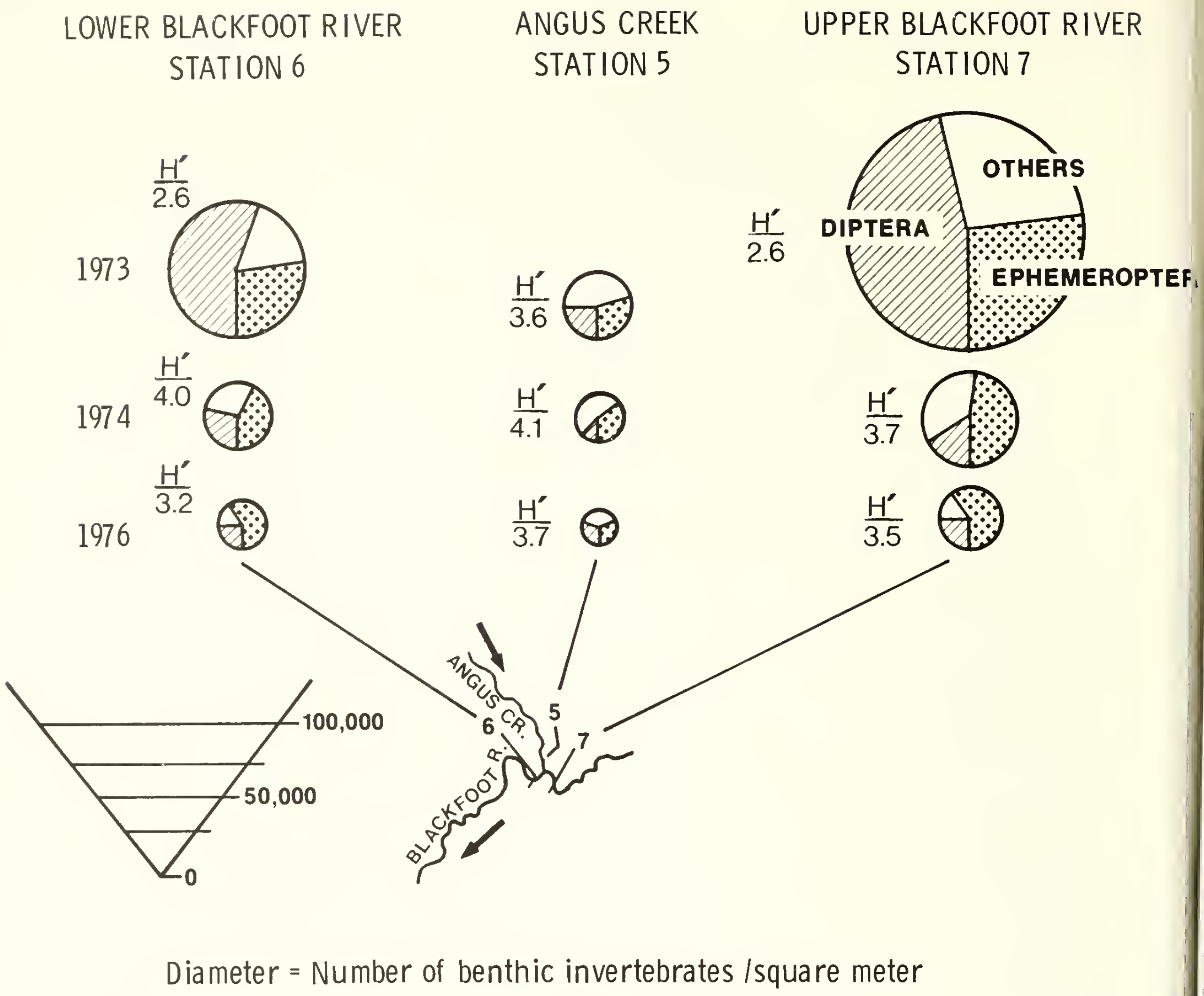

Figure 4.--Changes in benthic macroinvertebrates standing crops composition, and heterogeneity indices (H') at 3 selected stations (fall samples only).

Heterogeneity Indices

The makeup of the benthic macroinvertebrate community in a certain section of stream is a reflection of such factors as current velocity, channel substrate particle size, stream flow, water temperature, and food availability, as well as any abnormal environmental factors, such as silt, floods, and chemical and physical pollution that may influence the stream environment. Heterogeneity indices have been shown to be accurate indicators of adverse influences on stream ecosystems (Gislason 1971; Olive and Smith 1975); so indices differences occurring between sample stations and between stream communities can be used as indicators of environmental condition.

The Shannon-Weaver heterogeneity indices for all stations ranged from 2.6 to 4.3 with most values 3.1 or higher. The highest diversity values occurred in Angus Creek, the lowest in Blackfoot River.

A comparison of diversity indices at the upper Blackfoot stations can be made with published values. Wilhm (1970) furnishes a compilation of mean diversity indices for a variety of streams classified as clean, recovered, or polluted with various substances. In 21 streams listed as clean or recovered, mean diversity ranged from 2.6 to 4.6, whereas in 21 streams receiving pollution discharges, indices ranged from 0.4 to 1.6. The diversity indices for the Blackfoot streams fall well within the ranges of the clean or recovered streams.

DISCUSSION

Although benthic macroinvertebrate distributions in streams appear to be scattered and variable when collectively considered, more extensive sampling might reduce the number of discrepancies and reveal the presence of other invertebrates. The relative abundance of data will permit workers to measure changes in each stream's community composition.

Assessment of the general health of the upper Blackfoot River system can be made by comparing its community composition to those from other streams. Table 4 lists the number of discrete recognizable taxa in major classes and orders found in the Blackfoot system and several other southeastern Idaho streams. The Lost Rivers (Andrews and Minshall 1979) and Mink Creek (Newell and Shaw, unpublished [data on file at Idaho State University, Department of Biology]) receive minimal if any disturbance from human or agricultural sources. Although subject to an unknown degree of disturbance caused by livestock and irrigation, Deep Creek (Minshall and others 1973) is currently not considered seriously polluted, just intermittently disturbed. The upper and lower parts of the Portneuf River furnish an excellent contrast between healthy and degraded stream conditions (Minshall and Andrews 1973). The upper Portneuf is relatively undisturbed and supports a rich fauna. On the other hand, the lower Portneuf receives considerable amounts of sewage and toxic materials from urban, agricultural, and industrial sources and reductions in the biota parallel these additions. The total numbers of taxa ranged from 47 to 82 in the Blackfoot River and the tributaries studied. This range compares closely with the range of taxa (51 to 89) found in the relatively unpolluted streams listed. The total number of taxa in the lower Portneuf was 28, a considerable reduction from the upper Portneuf and considerably below the range for the Blackfoot streams, except Diamond Creek.

The range in numbers of taxa of Ephemeroptera (9 to 15), Plecoptera (10 to 12), and Trichoptera (7 to 17) in the Blackfoot streams compares very favorably with the same range of taxa in other southeastern Idaho streams (Ephemeroptera [5 to 20], Plecoptera [6 to 24], and Trichoptera [8 to 25]). These taxa are widely regarded as being highly sensitive to pollution. Comparable numbers of taxa in the lower Portneuf are Ephemeroptera 4, Plecoptera 1, and Trichoptera 3. The comparison indicates that the upper Blackfoot and its tributaries more closely resemble unpolluted streams of southeastern Idaho than polluted streams.

Table 4.--*The number of discrete, recognizable taxa of invertebrates in several southeastern Idaho streams is compared with the fauna of the upper Blackfoot River watershed*

Taxon	Diamond Creek	Kendall Creek	Angus Creek	Mill Creek	Blackfoot River	Lost River[1]	Mink Creek[2]	Deep Creek[3]	Upper Portneuf River[4]	Lower Portneuf River[4]
Acari	1	1	1	1	1	1	1	1	1	1
Amphipoda	--	1	2	--	2	2	1	2	2	2
Coleoptera	5	6	10	7	9	5	5	19	5	2
Diptera	8	11	15	13	9	6	12	11	5	4
Ephemeroptera	12	10	12	9	15	20	14	5	9	4
Hemiptera	--	--	2	--	1	--	--	5	1	--
Hirudinea	--	1	1	1	1	1	--	3	2	1
Lepidoptera	--	--	--	--	--	--	--	1	1	1
Lumbriculidae	1	1	1	1	1	--	--	1	--	--
Mollusca	--	6	6	6	6	3	4	7	6	4
Nematoda	--	--	--	--	--	--	--	1	1	--
Megaloptera	--	1	1	--	--	1	1	1	--	--
Odonata	--	--	--	--	--	--	--	5	2	3
Plecoptera	10	10	12	11	11	16	24	[5]1	6	1
Trichoptera	7	11	17	14	14	14	25	10	8	3
Tubificidae	1	1	1	1	1	--	1	1	1	1
Turbellaria	1	1	1	1	1	1	1	--	1	1
Totals	46	61	82	65	72	70	89	74	51	28

[1]Andrews and Minshall (1979).
[2]Newell and Shaw (unpublished) data at Idaho State University Department of Biological Sciences.
[3]Minshall and others (1973).
[4]Minshall and Andrews (1973).
[5]Only Plecoptera was collected.

A comparison of the macroinvertebrate fauna of the upper Blackfoot streams to that of streams polluted with organic and toxic wastes indicates gross dissimilarities. A septic zone fauna typical of streams polluted with organic sewage consists predominantly of oligochaetes, snails, rattail maggots, mosquitoes, and midge larvae. A recovery zone usually includes a lesser proportion of the septic zone forms and a larger proportion of blackfly larvae, mayfly nymphs, and caddis fly larvae (Gaufin and Tarzwell 1952; Gaufin 1956). Many of the typical recovery zone organisms were present in the Blackfoot River streams studied, but not in the abundance or relative percentages characteristic of organically degraded streams. A stream polluted with toxic inorganic wastes typically suffers a severe reduction in the number of species, sometimes to as few as eight or nine (Parsons 1960). Diamond Creek had from 18 to 29 taxa and could be characterized as depleted. The reason for this is unknown. The other streams had from 42 to 68 taxa and cannot be considered depleted in species.

The number and kinds of macroinvertebrate taxa and their distribution, the relative abundance of major taxonomic groups, the heterogenetic values, and the comparisons with other southeast Idaho streams indicate that the streams in the upper Blackfoot River generally are in a healthy condition. Stresses, however, appear to be present in the Diamond Creek drainage and the Lower Angus Creek area. The source of these is unknown at this time. Pollutants from mining, sediment from logging, and effects of livestock grazing are possibilities. Also, some of the stresses could be coming from natural causes. Biological observations will be needed to clear up questions arising from this study and to acquire a better set of temporal data to be used to determine if the system is changing and if so why.

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Photo Guides for Appraising Downed Woody Fuels in Montana Forests: How They Were Made

William C. Fischer

ABSTRACT

Eight series of color photographs have been published as three separate photo guides for appraising downed woody fuels in Montana forests. This note tells how these photo guides were constructed. The techniques used to determine the weight and size class distribution of downed woody fuels are given. The procedure used to rate potential fire behavior of the fuel shown in each photo is explained.

KEYWORDS: forest fuels, fuel appraisal

Fuel appraisal (Anderson 1974) is an important fire management task. It is a basic consideration when dispatching initial attack forces for fire suppression and an essential element for planning fuel management activities. Fuel appraisal also provides a basis for developing and evaluating fire management alternatives as part of land management planning.

Forest fuels can be appraised using techniques varying in precision of results and cost of application. Some techniques are suited to application over large areas while others are best applied to small areas. The photo guides described herein are proposed for application at the forest stand level. Precision is unknown but is expected to be intermediate when compared to other fuel appraisal techniques. Precision is probably higher for estimates of fire potential than it is for estimating fuel loads. Cost of application can vary from low to intermediate. This note describes the procedure used to construct the photo guides for appraising downed woody fuels in Montana forests (Fischer 1981a, 1981b, 1981c).

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[1]Research Forester, located at Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana.

PHOTO GUIDE CONSTRUCTION

The general procedure as well as many of the techniques used to construct the photo guides are similar to those proposed by the USDA Forest Service (1975) and used by Koski and Fischer (1979) and Maxwell and Ward (1976a, 1976b). There are, however, important differences. The above-cited photo series deal with recently created slash fuels while the photo guides described here deal primarily with fuels resulting from natural processes such as wind, snow, insects, disease, and competition for light and moisture; old logging and thinning slash is also included since it is now a part of the natural fuel complex. Another difference is the method used to predict potential fire behavior. Maxwell and Ward (1976a, 1976b) used the old Rate of Spread-Resistance to Control fuel type rating. Koski and Fischer (1979) used Rothermel's (1972) mathematical model. For the guides described here, experienced judgment of fuel and fire behavior experts is used to evaluate fire behavior potential.

Location of Camera Points

Camera points were located in recently undisturbed forest stands. Large blocks of such stands were sought out and camera points established to reflect the different fuel conditions found in each forest cover type present in the drainage.

Layout of Photo Plots

The area within the field of view of a camera installed at the camera point essentially defined the photo plot. For fuel inventory purposes, three transects were established in the photo plot. These transects had a common beginning at the photo point (fig. 1). The location and length of the transects were determined with the aid of the camera used to photograph the plot. The procedure followed to lay out the plot and its transects was:

1. Set up tripod over the camera point.

2. Mount camera on tripod.

3. Composed desired photo on the camera focusing screen or through the camera viewfinder. Lock camera in this position.

4. Install plot marker (fig. 2) 20 ft (6.10 m) in front of the center of the field of view.

5. Extend a straight line from the camera point, through the plot marker, to farthest point where surface fuels can still be discerned on the camera focusing screen or through the camera viewfinder (fig. 1). Mark this point with a stake.

6. Establish right and left transects by running lines from the camera point to the right and to the left edge of the camera's field of view (fig. 1). Transect length was the same as determined for the center transect. Mark both points with stakes.

While the transect length within a plot was the same, it did vary between plots. Transect length depended on the camera's ability to discern surface fuels. Consequently, transect length will vary with amount of undergrowth and other factors affecting the visibility of the forest floor. Transect length varied between 50 and 100 ft (15.2 and 30.5 m), but more often than not it was about 70 ft (21.3 m).

Figure 1.--Location of transects on photo plot.

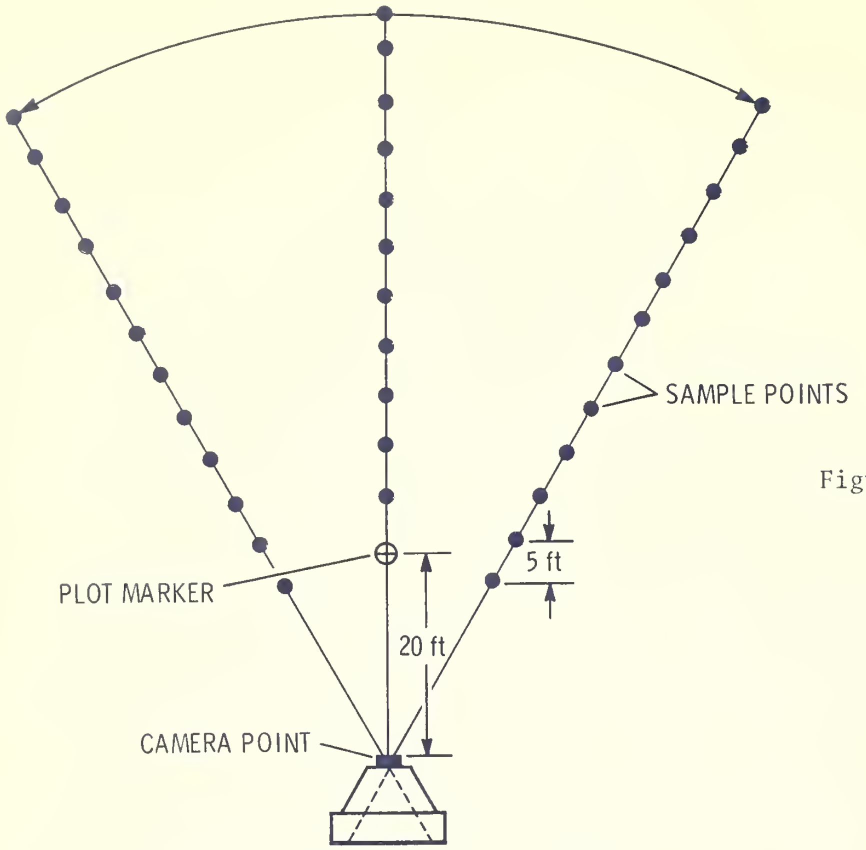

Figure 2.--Location of sampling points on photo plot.

Photographing the Plot

All photography of the plot was done with the camera mounted on a tripod installed over the camera point. Identical photos were taken of each plot using color print film, black an white print film, and color slide film. A Pentax[2] 35 mm camera with a wide-angle (35 mm) le was used for color slides. Kodak Ektachrome-X film (ASA 64) and High Speed Ektachrome (ASA 160) was used most often for color slides. A Mamiya 6X7 cm shutter-type SLR camera with a 5 mm lens produced the prints. The Mamiya allowed interchanging film holders, which facilitat getting both color and black and white photos with the same camera. About 25 of the plots were photographed using Rolliflex cameras, one loaded with color film and one with black and white film. Both produced satisfactory prints. Color slides also produced satisfactory color prints. Kodak Vericolor II Professional Type S 120 roll film (ASA 100) was used for color prints, and Kodak Tri-X Pan 120 roll film (ASA 400) for black and white prints.

The sequence for photographing the plots was:

1. Set up tripod over the camera point and mount roll film camera on it. (The roll film camera was always used first so the photo could be composed on its focusing screen rath than through the viewfinder of the 35 mm camera.)

2. Compose photograph and lock camera in position.

3. Install plot marker with correct plot number.

4. Lay out plot as indicated in previous section.

5. Take photos using color print film and then black and white print film.

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[2]The use of trade, firm, or corporation names in this publication is for the informatio and convenience of the reader. Such use does not constitute an offical endorsement or appro by the U.S. Department of Agriculture of any product or service to the exclusion of others w may be suitable.

6. Remove camera from tripod and install 35 mm camera in its place.

7. Center camera using plot marker as a guide.

8. Take photo using color slide film.

9. Remove plot marker and take the camera and tripod down.

Plot layout and photography was usually done separately from plot inventory. That is, one crew did the photography and layout while another crew followed behind doing the data collection. Consequently, plot location was recorded on a map and the camera point and transect end point (stakes) were well marked with a flagging tape. The route from the road to the camera point was also well marked with flagging tape.

PLOT INVENTORY

The following information was collected at each plot by the inventory crew:

1. Forest cover type as defined by the Society of American Foresters (1954).

2. Montana forest habitat type as defined by Pfister and others (1977). Pfister's field form was used for this purpose.

3. Age of overstory dominants using an increment borer.

4. Elevation using a barometer.

5. Aspect using a compass.

6. Fuel loading by size class, duff depth, average diameter of fuels 3 inches (7.62 cm) r greater in diameter, percent rotten for 3-inch (7.62-cm) or greater diameter fuels, and olume of sound material 3 inches (7.62 cm) or greater in diameter.

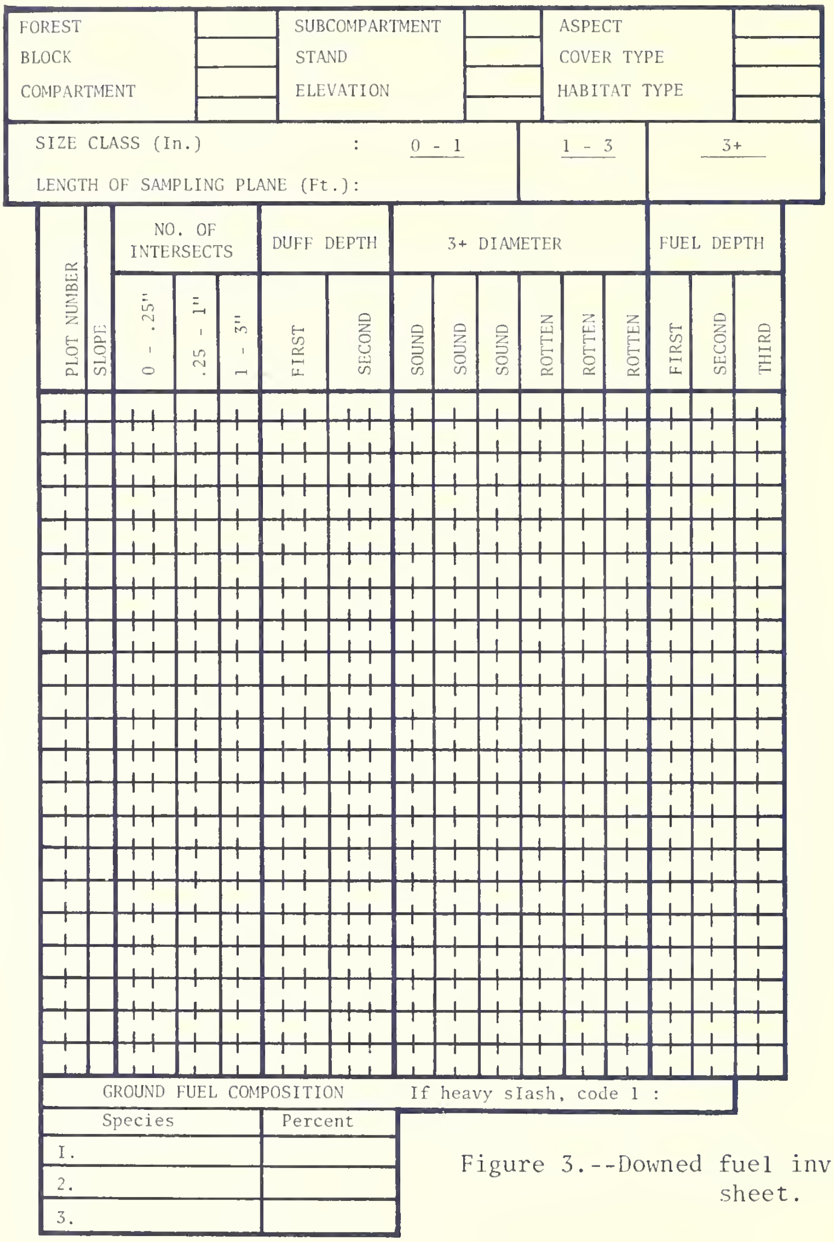
The fuel inventory field procedure developed by Brown (1974) was used to obtain all of he above-mentioned fuel information. Fuel inventory points were installed along each of the hree transects established during plot layout (fig. 1). The first point along each transect as installed 20 ft (6.10 m) from the camera point. Additional points were located at 5 ft 1.52 m) intervals along each transect (fig. 2). This design resulted in from 20 to 40 ample points per photo plot. Sampling plane lengths used at each point were as follows:[3]

Fuel size class	Sampling plane length
0-0.25 inch (0-0.64 cm)	4 ft (1.22 m)
0.25-1.00 inch (0.64-2.54 cm)	4 ft (1.22 m)
1.00-3.00 inches (2.54-7.62 cm)	8 ft (2.44 m)
3.00 inches or greater (7.62 cm or greater)	20 ft (6.10 m)

Sampling plane direction was random but kept within the photo plot. That is, sampling lane direction at points along the right and left transects was always kept to the left and ight of these lines respectively. This, and locating the first point on each transect 20 t (6.10 m) from the camera point, insured that the fuel inventory reflected only what was seen y the camera.

[3]Personal communication, James K. Brown, Northern Forest Fire Laboratory, Missoula, Mont.

The downed fuel inventory field sheet developed by Brown (1974) was used to record fuel data collected on each plot (fig. 3).


DOWNED FUEL INVENTORY

FOREST
BLOCK
COMPARTMENT
SUBCOMPARTMENT
STAND
ELEVATION
ASPECT
COVER TYPE
HABITAT TYPE

SIZE CLASS (In.) : 0 - 1 | 1 - 3 | 3+
LENGTH OF SAMPLING PLANE (Ft.):

PLOT NUMBER	SLOPE	NO. OF INTERSECTS			DUFF DEPTH		3+ DIAMETER						FUEL DEPTH		
		0 - .25"	.25 - 1"	1 - 3"	FIRST	SECOND	SOUND	SOUND	SOUND	ROTTEN	ROTTEN	ROTTEN	FIRST	SECOND	THIRD

GROUND FUEL COMPOSITION   If heavy slash, code 1 :

Species	Percent
1.	
2.	
3.	

Figure 3.--Downed fuel inventory field sheet.

Fire Potential Rating

Each plot was rated in terms of its potential fire behavior for an "average bad" fire weather situation. The assumed fire weather situation was: temperature - 85° to 90° F (29° to 32° C), relative humidity - 15 to 20 percent, windspeed - 10 to 15 mi/h (17 to 26 km/h), and last measurable rain - 4 weeks ago.

Five elements of fire behavior were rated: rate of spread, intensity, torching, crowning and resistance to control. In addition, an overall fire potential rating was assigned to each plot. The rating was subjective. Managers and researcher with experience in prescribed fire and fire control assigned adjective ratings according to the following definitions:

Rate of Spread

Nil--fire cannot sustain itself.

Low--spread will be slow and discontinuous.

Medium--uniform spread possible but can be stopped by aggressive ground attack with hand tools.

High--spread will be rapid; indirect attack on fire front may be required for control.

Extreme--spread will be explosive; little chance of control until weather changes.

Intensity

Nil--fire cannot sustain itself.

Low--cool fire; very little hot spotting required for control.

Medium--fire will burn hot in places; aggressive hot spotting with hand tools likely to be successful.

High--too hot for sustained direct attack with hand tools; aerial tankers or large ground tanker required to cool fire front.

Extreme--direct ground attack not possible; air or ground tanker attack likely to be ineffective.

Torching

Nil--no chance of torching.

Low--occasional tree may torch-out.

Medium--pole-sized understory trees likely to torch-out.

High--most of understory and occasional overstory trees likely to torch-out.

Extreme--entire stand likely to torch-out.

Crowning

Nil--sustained spread in crowns will not occur.

Low--sustained spread in crowns unlikely.

Medium--some crowning likely but will not be continuous.

High--sustained crowning likely.

Extreme--sustained crowning will occur.

Resistance to Control Action

Nil--no physical impediments to line building and holding.

Low--occasional tough spots but not enough to cause serious line building and holding problems.

Medium--hand line construction will be difficult and slow but dozers can operate without serious problems.

High--slow work for dozers, very difficult for hand crews; hand line holding will be difficult.

Extreme--neither dozers nor hand crews can effectively build and hold line.

Overall Fire Potential

Nil--fire will not sustain itself.

Low--fire can be easily controlled by several smokechasers with hand tools.

Medium--aggressive crew-sized (6-10) persons initial attack required for successful control.

High--aggressive crew-sized (25 persons) initial attack with substantial reinforcement required for successful control; 10 percent chance that control action will fail.

Extreme--90 percent chance that control action will fail.

Mathematical models designed to predict fire spread and intensity were not used to evalua fire potential. Existing mathematical models assume uniform and continuous fuels. Such conditions are the exception rather than the rule in recently undisturbed forest stands in Montana.

All fire potential ratings were done in the field at the photo plot. Most plots were rated by three to five people. A few plots were rated by only two people and some by as many as six. A total of 27 different raters participated. Ratings were, however, done individually without consultation among the raters. The field sheet used by the raters is shown in figure 4.

The fire potential rating method used in developing the photo guides is not without precedent in the Northern Rocky Mountains. It is in many ways a refinement of the time-teste concept of fuel rating introduced more than 40 years ago by L. G. Hornby (1936).

Data Analysis and Summary

Fuel inventory data were analyzed and summarized using the computer program DFINV.[4] Fire potential ratings assigned to each plot by the different raters were averaged to obtain a single set of ratings for the plot. This was done by assigning the following values to eac objective rating:

Nil - 1

Low - 2

Medium - 3

High - 4

Extreme - 5

If the average value was halfway between two ratings, it was rounded up or down depending on remarks entered by raters on the field sheet (fig. 4).

[4]Johnston, Cameron M., July 1975. Downed woody material inventory computer program writ up. On file at Northern Forest Fire Laboratory, Missoula, Mont. Program is located at the USDA Computer Center, Fort Collins, Colo., and is available to all who have access to this facility.

FIRE POTENTIAL EVALUATION STUDY RATING SHEET

STAND NO. ____________

DATE ________________

RATER _______________

INSTRUCTIONS: Circle Appropriate Rating and Give Your Reason(s)

1. RATE OF SPREAD: Nil Low Medium High Extreme
   WHY? ____________________

2. INTENSITY: Nil Low Medium High Extreme
   WHY? ____________________

3. TORCHING: Nil Low Medium High Extreme
   WHY? ____________________

4. CROWNING: Nil Low Medium High Extreme
   WHY? ____________________

5. RESISTANCE TO CONTROL ACTION (Physical - Not Intensity):
   Nil Low Medium High Extreme
   WHY? ____________________

6. OVERALL HAZARD: Nil Low Medium High Extreme
   COMMENTS: ____________________

Figure 4.--Field sheet for rating fire potential.

National fire danger rating system fuel models were assigned by evaluating the photograph in terms of the fuel model descriptions provided by Deeming and others (1977). Similarly, stylized fuel models were assigned according to the fuel model descriptions provided by Albini (1976). Fire ecology group assignment was based on the grouping of Montana habitat types (Pfister and others 1977) developed by Davis and others (1980).

Plot data and information were summarized on a data sheet (fig. 5) that accompanies each photo in the guides. Fuel loadings are recorded to the nearest 0.1 ton/acre for all size classes. Actually, reasonable significant figures for loading are:

-- the nearest 0.1 ton/acre for loading less than 10 tons/acre,

-- the nearest 1.0 ton/acre for loadings between 10 and 50 tons/acre, and

-- the nearest 5.0 tons/acre for loadings greater than 50 tons/acre.

DATA SHEET

Stand No. 35A

FOREST COVER TYPE: SAF NO. 218, Lodgepole pine

MONTANA HABITAT TYPE: NO. 720, Subalpine fir/blue huckleberry (ABLA/VAGL)

DOWN & DEAD WOODY FUEL LOADINGS

Size Class (Inches)	Weight T/ac	Weight *Kg/m²*
0-0.25	0.3	0.07
0.25-1	1.2	0.27
1-3	5.1	1.14
Subtotal 0-3	6.6	1.48
3-6	4.3	0.96
6-10	1.1	0.25
0-20	0	0
20+	0	0
Subtotal 3+	5.4	1.21
Total	12.0	2.69

FDRS FUEL MODEL	STYLIZED FUEL MOD. Albini (1976)
H/G	**8/10**

OTHER FUEL DATA

average duff depth; 2.4 in

6.10 *cm*

average diameter, 3+fuels

3.8 in

9.65 *cm*

Percent rotten, 3+fuels: 16 %

Volume of sound 3+fuels:

360 ft^3/ac

25.2 m^3/ha

STAND AND SITE DATA

AGE of overstory dominants:

PICO 123 yrs.

Average slope: 11 %

Aspect: Northwest

Elevation: 6090 ft 1856 *m*

Fire Ecology Group: seven

Remarks:

ESTIMATED FIRE POTENTIAL

Based on an average bad day:
85-90° temp., 15-20% R.H., 10-15 mi/h wind, 4 week since rain.

Rate of spread	Medium
Intensity	Low
Torching	Low
Crowning	Low
Resistance to control	Low
Over all Fire Potential	Low

STAND LOCATION

National Forest: Lewis and Clark

Ranger District: White Sulphur Springs

Drainage: Fourmile Creek

Photo taken: 8/10/78

By: W. C. Fischer

Figure 5.--Plot photo and accompanying data sheet.

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Reno, Nevada (in cooperation with the University of Nevada)

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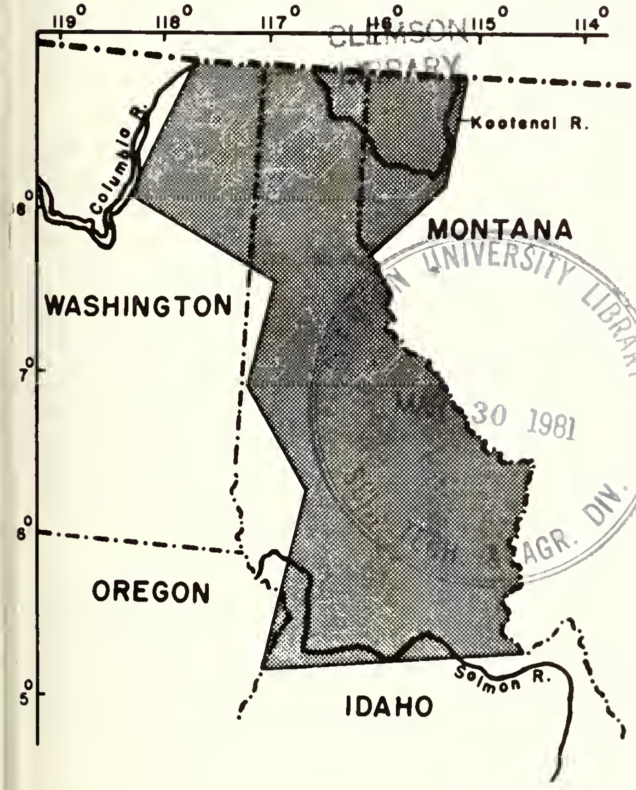
January 1981

SEED TRANSFER GUIDELINES FOR DOUGLAS-FIR IN NORTH IDAHO

G. E. Rehfeldt[1]



[1]Plant Geneticist, located at Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

USDA Forest Service Research Note INT-300

Douglas-fir seeds for reforestation in Northern Idaho (see map) may be transferred from the collection area:

(1) ± 325 feet (100 m) elevation;

(2) ± 0.5 degrees latitude (about 30 miles [48 km]);

(3) without regard to habitat type;

(4) without regard to longitude.

Thus, seed zones should encompass about 650 feet (200 m) elevation and 1 degree of latitude.

Whenever trees are planted, there is some risk of maladaptation. Even with adherence to the guidelines presented above, a planted tree may not be adapted to the environment in which it is planted. The risk of maladaptation can be assessed by growing trees from various seed sources in environments that represent anticipated transfer distances. Then, the risk can be expressed as a percentage that populations differ genetically across environmental gradients.

Figures 1 and 2 show the differences expected between seedlings derived from natural reproduction and planted trees that have been transferred various distances from their origin. For instance, as compared with a local seed source, trees transferred 1 000 m (3,050 ft) upward in elevation are expected to possess 26 percent greater growth potential and 15 percent less spring bud set; but they are expected to suffer 31 percent more fall frost injury and 19 percent more spring frost injury and be 31 percent less winter hardy (fig. 1). Even transfers between single seed zones are expected to differ from indigenous sources by about 5 percent in growth potential, 3 percent in spring bud set, 6 percent in fall frost injury, 4 percent in spring frost injury, and 6 percent in winter cold hardiness.

Similarly, transfers of seed to locations north or south of their origin are associated with a risk of maladaptation. Transfers across a single seed zone of 1 degree latitude should differ from indigenous sources by 3 percent in growth potential, 4 percent in spring bud set, 2 percent in spring frost injury, and 6 percent in winter cold hardiness (fig. 2).

These seed transfer guidelines reflect current data. Future research may either refine these limits or uncover additional geographic and ecologic factors that should be used to control seed transfer. Nevertheless, because patterns of genetic differentiation among populations of Douglas-fir are so strongly defined, current guidelines should be put into practice.

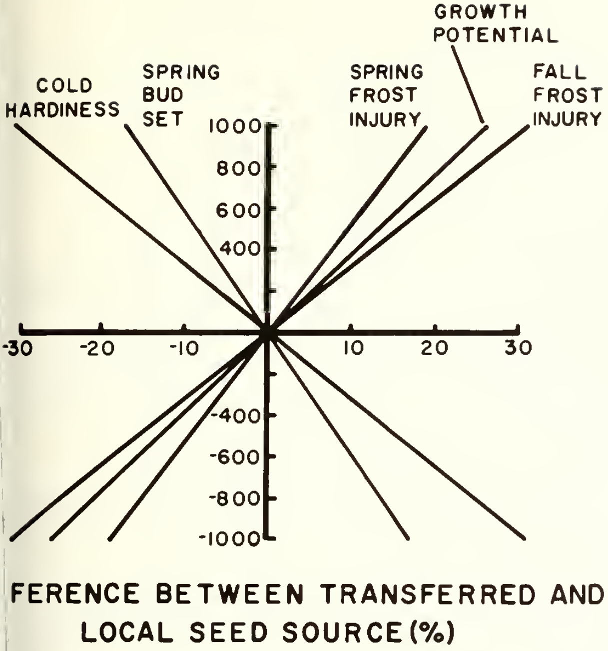


Figure 1.—Percentage differences expected between indigenous seed sources and sources transferred various distances in elevation for several characters.

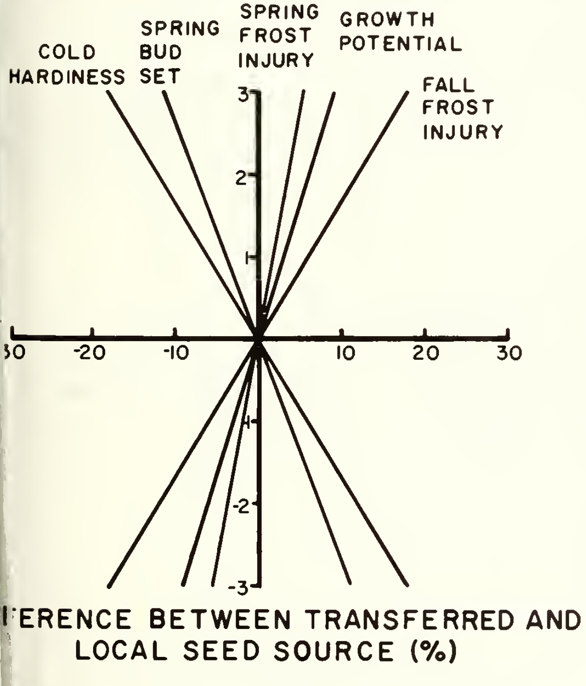


Figure 2.—Percentage differences expected between indigenous seed sources and sources transferred various distances in latitude for several characters.

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USDA FOREST SERVICE
Research Note INT-301

INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507–25th STREET, OGDEN, UTAH 84401

December 1980

POTTING MEDIA FOR *ATRIPLEX* PRODUCTION UNDER GREENHOUSE CONDITIONS

Robert B. Ferguson[1]

ABSTRACT

*A potting medium composed of 50 percent sphagnum moss peat, 30 percent arcillite aggregate, and 20 percent vermiculite is recommended for growing Bonneville saltbush (*Atriplex bonnevillensis *Hanson) in containers. This medium may be satisfactory for other plant species native to alkaline soils of semiarid areas. Of 39 potting media evaluated, no single formulation was clearly superior. Media containing sphagnum moss peat, vermiculite, and arcillite, however, were judged more suitable from the standpoint of plant yield and water retention than media composed of sphagnum moss peat, vermiciulite, and perlite. Although some soil-amended media produced slightly larger seedlings than soilless media, the decreased seedling emergence and greater mortality from damping-off in the former made soilless media preferable.*

KEYWORDS: container-grown plants, potting media, *Atriplex bonnevillensis.*

Many plants native to semiarid lands of the eat Basin and Colorado Plateaus are useful in e reclamation of surface-mined areas. Shrub ecies will play an important part in such rec-nation. In semiarid areas, transplanting con-ner-grown planting stock is often more suc-ssful than establishing shrubs by direct seeding (Frischknecht and Ferguson 1979).

As the demand for planting stock of native shrubs increases, plant propagators will need to know the best ways to grow high-quality plants for transplanting.

[1]Range scientist located at Intermountain Station's Shrub iences Laboratory, Provo, Utah.

Potting media composed of sphagnum moss peat and vermiculite are commonly used for growing containerized plants (Boodley and Sheldrake 1967, 1973; Phipps 1974; Cayford 1972; and Owston 1972). Perlite is sometimes used with moss peat instead of vermiculite. Many growers continue to use growing media having a large proportion of soil or sand (Augustine and others 1979). The great weight of soil or sand, however, adds to the expense of handling in the greenhouse, shipping to the field planting site, and in planting operations.

This study was designed to learn more about potting media useful for growing Bonneville saltbush (*Atriplex bonnevillensis*), which is one of the more promising native North American species o *Atriplex* for reclaiming surface-mined land (Frisch knecht and Ferguson 1979).

EXPERIMENTAL METHODS

The potting media evaluated in this study wer composed of various combinations of Canadia sphagnum moss peat, horticultural grade verm culite, horticultural grade perlite, arcillite aggre gate, and nonpasteurized topsoil from a salt des ert shrub community in central Utah (table 1).

Arcillite is a montmorillonite clay that is calcine to stabilize the aggregate. The brand used in thi

Table 1.—Number of Bonneville saltbush seedlings emerging, percent mortality from damping-off, and mean ovendry weight of plant tops, for 19 potting media with and without soil, and for soil alone

Mix number	Composition[1] SMP/V/P/A	Number of seedlings emerging	Percent damping-off	Mean ovendry weight[3]
	Percent			*Grams*
1	67/33/0/0	158 (59)[2]	1 (20)	0.36 (0.50)
2	67/0/33/0	162 (51)	2 (26)	.21 (.40)
3	67/0/0/33	183 (109)	2 (17)	.32 (.32)
4	60/20/20/0	116 (94)	3 (8)	.32 (.34)
5	60/20/0/20	163 (114)	1 (12)	.28 (.34)
6	50/50/0/0	140 (111)	2 (4)	.34 (.34)
7	50/20/30/0	168 (79)	1 (18)	.26 (.28)
8	50/20/0/30	195 (177)	5 (6)	.40 (.50)
9	40/40/20/0	164 (60)	4 (17)	.26 (.34)
10	40/40/0/20	224 (103)	2 (29)	.40 (.52)
11	35/35/30/0	244 (47)	1 (11)	.32 (.36)
12	35/35/0/30	286 (248)	5 (12)	.40 (.36)
13	33/67/0/0	229 (150)	12 (25)	.30 (.29)
14	20/60/20/0	364 (119)	5 (31)	.24 (.38)
15	20/60/0/20	347 (246)	9 (14)	.37 (.34)
16	20/50/30/0	257 (94)	3 (22)	.33 (.35)
17	20/50/0/30	421 (176)	4 (26)	.31 (.43)
18	0/67/33/0	215 (375)	3 (7)	.25 (.23)
19	0/67/0/33	439 (213)	7 (32)	.30 (.32)
Soil	0/0/0/0	139 —	19 —	.19 —

[1]Sphagnum moss peat (SMP), vermiculite (V), perlite (P), arcillite (A).
[2]Figures in parentheses are for same mixture composition plus 5 percent by volume of soil.
[3]Mean ovendry weight of aerial part of 20 plants harvested after 4½ months.

study was Turface, a product of Wyandotte Chemicals Corporation, Wyandotte, Mich.[2] Percent of the aggregates passing through 8-, 2-, 1-, and 0.5-mm sieves equalled 100, 78, 31, and 10, respectively.

Nineteen different media of two or more of the above soilless ingredients were compared with the same 19 media amended with an additional 5 percent, by volume, of topsoil. The small amount of topsoil was added to determine whether seedling growth would be increased without adding appreciably to the weight of the potting medium. Topsoil alone was also included in the experiment.

Potting medium ingredients were mixed thoroughly by hand and dampened to a consistency suitable for filling the containers. All media except the topsoil were supplemented with the following amounts of nutrient amendments per cubic foot (28.3 liter) of medium: agricultural lime, 200 g; calcium nitrate, 27 g; gypsum, 84 g; treble superphosphate, 21 g; Osmocote (18-6-12), 36 g; fritted trace elements (FTE #503), 3.2 g; chelated iron, 1 g; and surfactant (Triton N-101),[2] 2 g.

The experimental design consisted of 39 treatments (media) each with two replications. Seventy-eight trays of seedlings (two per treatment) were arranged completely at random on one greenhouse bench. Seedlings were grown in Spencer-Lemaire Rootrainers (Five-type).[2] This type of plastic container has five cavities, each with a volume of 60 cc, and dimensions of 1 inch X 1 inch X 4½ inches (2.54 cm X 2.54 cm X 11.4 cm). Thirteen containers are held in each tray, making a total of 65 cavities per tray.

Six Bonneville saltbush seeds were sown in each container cavity in mid-November. Seeded trays were arranged in random sequence on the greenhouse bench and their positions rotated at ?-week intervals during the study.

Seedlings were grown for a 4½-month period. No additional fertilizer was provided during the study period. Plants were watered as needed with tapwater having a pH of 7.3. Day length was extended to 16 hours with "Grolux" fluorescent lighting.[2]

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Data on seedling emergence were recorded 17 days following seeding. Data on mortality caused by damping-off were recorded at 17 days and 31 days following seeding. Seedlings were thinned to one per container cavity 31 days following seeding. At the end of the study period, 20 seedlings were harvested from each tray and mean oven-dry weight determined.

Water absorption and retention capacity of media was determined by periodic weighing following saturation. This phase of the study was done independently of the greenhouse phase. Media were packed in Five-type Rootrainers[2] in the same manner used when growing the saltbush seedlings. Containers were kept in the laboratory at room temperatures for a 7-week period.

RESULTS

Seedling emergence and early mortality.— Soilless potting media produced an average of over twice as many (109 percent) emergent seedlings as media containing 5 percent topsoil. In soilless media, as the ratio of moss peat to vermiculite decreased, the number of emergent seedlings increased (table 1). In media containing topsoil, however, seedling emergence did not appear to be related to the moss peat/vermiculite ratio. In both soilless and soil-amended media, seedling emergence tended to be greater when the medium was composed of moss peat, vermiculite, and arcillite compared to moss peat, vermiculite, and perlite.

Mortality of emergent seedlings caused by damping-off fungi was much greater in the media with soil than in soilless media (table 1). Mortality in the 19 soil-amended media averaged 18 percent (range = 4 to 32 percent); the average mortality for the 19 soilless media was 4 percent (range=<1 to 12 percent). Seedling mortality from damping-off was 19 percent in a growing medium of 100 percent topsoil.

In the four media that contained no moss peat, many seedlings emerged with the cotyledons still bound in the husk of the utricle; so the hypocotyl did not penetrate the potting medium well. Some of these seedlings eventually died. Seedlings emerged normally in all other media.

Seedling growth.—Ovendry weight of the aerial portion of the seedlings was obtained after a 4½-month growing period. Analysis of variance indicated a highly significant difference ($p = <0.01$) in weight among media. Keul's multiple range test (Snedecor 1956) was used to separate significantly different means (fig. 1, $p =<0.05$). Media No. 8, No. 10, and No. 12, with and without topsoil, were all above average in terms of plant weight. Seven of the top 10 mean plant weights were produced by media containing arcillite (table 1). Six of the top 10 mean plant weights were produced by media amended with topsoil. Topsoil may have added some plant nutrients, may have introduced beneficial mycorrhizae, or increased cation exchange capacity of these media.

The five highest mean plant weights among the soilless media (No. 8, No. 10, No. 12, No. 15, and No. 1) were all produced by media that had a pH between 6.0 and 6.5 and an EC_e between 1.9 and 4.6 mmhos/cm at the end of the experiment. The remaining 14 soilless media exhibited either a pH or EC_e outside this range. Among media amended with soil, plant weight, as measured at the end of the experiment, was not consistently related to either pH or EC_e.

Water absorption and retention.—When at container capacity, the various test media absorbed from 30 to 220 percent more water than did the topsoil alone (table 2). Moss peat is the primary water-absorbing component in such mixtures. As the proportion of moss peat in the mixtures decreased, the total amount of water held (and retained with the passage of time) generally decreased. When the percentage of moss peat in the mixture was less than 40, the combination of moss peat, vermiculite, and arcillite tended to retain more water against the forces of evaporation than the combination of moss peat, vermiculite, and perlite (table 2).

Medium number	Mean weight
Soil	0.19
2	.21
18-S	.23
14	.24
18	.25
7, 9	.26
5, 7-S	.28
13-S	.29
13, 19	.30
17	.31
3, 4, 11, 3-S, 19-S	.32
16	.33
6, 4-S, 5-S, 6-S, 9-S, 15-S	.34
16-S	.35
1, 11-S,12-S	.36
15	.37
14-S	.38
8, 10, 12, 2-S	.40
17-S	.43
1-S, 8-S	.50
10-S	.52

Figure 1.—Mean ovendry weight, in grams, o Bonneville saltbush seedling tops grown in 1 different potting media with and without soil an in soil alone. Any two-means paralleled by th same line are not significantly different (α p = 0.05).

Media No. 5 through No. 10 (except No. 7) were superior to other media in long-term water retention. Media No. 6, No. 8, and No. 10 were most resistive to evaporative water loss. Two of these media contained arcillite, which holds water by both absorption and adsorption because of the capillaries in each particle. This characteristic of arcillite would be of increasing value with respect to water retention capacity as the height of the container increased. As noted by Van Bavel and others (1978), the average water content of a container of soil or similar material decreases with increasing container height once drainage ceases. The relative ability of a potting medium to resist water loss to physical forces may be important should a dry period follow planting.

Table 2.—Water retention characteristics of 19 potting media with and without soil and of soil alone

Mix number	Composition[1] SMP/V/P/A	Relative weight at container capacity	Volume percent[2]	Percent of water retained[3] After 1 week	After 7 weeks
	Percent				
1	67/33/0/0	[4]1.4 (1.6)	73 (81)	74 (76)	2 (7)
2	67/0/33/0	1.3 (1.5)	72 (70)	76 (75)	5 (7)
3	67/0/0/33	1.7 (1.8)	74 (74)	75 (79)	9 (12)
4	60/20/20/0	1.4 (1.5)	75 (67)	82 (77)	16 (14)
5	60/20/0/20	1.6 (1.7)	69 (72)	77 (80)	15 (18)
6	50/50/0/0	1.5 (1.6)	78 (78)	78 (81)	18 (20)
7	50/20/30/0	1.3 (1.5)	69 (71)	76 (75)	11 (14)
8	50/20/0/30	1.8 (1.9)	76 (74)	79 (80)	19 (20)
9	40/40/20/0	1.5 (1.5)	76 (71)	77 (78)	17 (16)
10	40/40/0/20	1.6 (1.8)	68 (68)	79 (79)	19 (16)
11	35/35/30/0	1.3 (1.5)	63 (66)	73 (73)	14 (13)
12	35/35/0/30	1.7 (1.8)	67 (68)	74 (75)	15 (13)
13	33/67/0/0	1.5 (1.6)	76 (74)	74 (73)	12 (9)
14	20/60/20/0	1.2 (1.4)	60 (62)	64 (68)	3 (5)
15	20/60/0/20	1.4 (1.7)	63 (68)	73 (75)	10 (12)
16	20/50/30/0	1.1 (1.3)	54 (61)	70 (70)	12 (11)
17	20/50/0/30	1.5 (1.8)	64 (69)	76 (74)	15 (11)
18	0/67/33/0	1.0 (1.3)	47 (58)	70 (72)	9 (7)
19	0/67/0/33	1.5 (1.6)	62 (61)	80 (77)	18 (15)
Soil	0/0/0/0	2.7 —	36 —	68 —	10 —

[1]Sphagnum moss peat (SMP), vermiculite (V), perlite (P), arcillite (A).
[2]Percent of the volume of the container occupied by water 24 hours after saturation to container capacity.
[3]Based on container capacity being equal to 100 percent.
[4]Figures in parentheses are for same mixture composition plus 5 percent by volume of soil.

Hydrogen ion concentration and electrical conductivity.—Both pH and electrical conductivity of the saturation extract (EC_e) of all potting media were measured at the beginning and end of the experiment (table 3).

All media, except No. 8, No. 10, No. 12, No. 15, No. 17, No. 12-S, and No. 18-S, showed an increase in pH during the study period. Except for No. 18-S, these media contained 50 percent or less moss peat plus vermiculite, and arcillite. While media with arcillite tended to have higher pH values than media without arcillite at the beginning of the study, the buffering property of arcillite prevented subsequent increases in pH.

Table 3.—Hydrogen ion concentration and electrical conductivity of saturation extracts of 19 potting media with and without soil, and of soil alone, at the beginning and end of a 4½-month growing period

Mix number	Composition[1] SMP/V/P/A	pH of saturation extract		EC_e of saturation extract	
		Initial	Final	Initial	Final
	Percent			*mmhos/cm*	
1	67/33/0/0	[2]6.0 (6.6)	6.9 (7.5)	1.3 (1.5)	2.0 (0.9)
2	67/0/33/0	6.0 (6.4)	6.8 (7.4)	.7 (.9)	1.6 (2.5)
3	67/0/0/33	6.4 (7.1)	7.1 (7.7)	1.0 (.7)	1.8 (.6)
4	60/20/20/0	5.4 (6.4)	6.8 (7.3)	3.6 (.9)	1.2 (1.2)
5	60/20/0/20	6.4 (6.8)	7.2 (7.5)	.8 (.9)	1.4 (1.8)
6	50/50/0/0	5.7 (6.4)	7.3 (7.5)	2.8 (.8)	1.5 (1.5)
7	50/20/30/0	5.6 (6.4)	7.2 (7.5)	3.4 (.9)	1.0 (1.2)
8	50/20/0/30	6.2 (6.8)	6.0 (7.2)	2.9 (.9)	4.3 (3.5)
9	40/40/20/0	6.4 (6.9)	7.7 (7.6)	.8 (.4)	.6 (1.1)
10	40/40/0/20	6.4 (6.9)	6.0 (7.4)	1.6 (.9)	3.4 (1.2)
11	35/35/30/0	6.4 (6.7)	7.4 (7.7)	.8 (.6)	.9 (.9)
12	35/35/0/30	6.5 (6.9)	6.1 (6.7)	2.7 (1.5)	1.9 (8.4)
13	33/67/0/0	5.9 (7.0)	7.2 (7.8)	1.5 (.6)	1.0 (1.4)
14	20/60/20/0	6.0 (7.0)	7.6 (7.9)	3.4 (.7)	.9 (1.4)
15	20/60/0/20	6.5 (7.0)	6.5 (7.4)	2.2 (.9)	4.6 (4.0)
16	20/50/30/0	6.3 (6.9)	7.7 (7.7)	.9 (.7)	1.2 (1.1)
17	20/50/0/30	6.5 (7.4)	6.4 (7.5)	2.8 (1.5)	8.1 (3.3)
18	0/67/33/0	7.3 (7.8)	7.4 (7.5)	1.1 (.4)	3.0 (2.0)
19	0/67/0/33	7.4 (7.4)	7.5 (7.6)	1.0 (.9)	1.7 (1.7)
Soil	0/0/0/0	9.1 —	8.1 —	.2 —	5.1 —

[1]Sphagnum moss peat (SMP), vermiculite (V), perlite (P), arcillite (A).
[2]Figures in parentheses are for the same mixture composition plus 5 percent by volume of soil.

CONCLUSIONS

Bonneville saltbush attained greater size in soilless media containing arcillite than in media without it. When 5 percent, by volume, of topsoil (pH = 9.1) was added to the same series of media, three of the five media yielding the heaviest plants contained arcillite. Our study has shown that the inclusion of arcillite in a medium of fertilized moss peat and vermiculite tends to stabilize pH of the media. Measurements of the electrical conductivity of the saturation extract showed that media with arcillite also exhibited greater salinity than did media without arcillite.

Although some potting media containing 5 percent soil produced slightly larger seedlings than did soilless media, the decreased seedling emergence and greater mortality from damping-off in soil-amended media make soilless media preferable.

Field planting of container-grown planting stock requires that the root system of the plant form a cohesive plug which can be removed from the container with minimal disturbance to the roots. For this reason, potting media should contain a minimum of 40 percent moss peat. Potting media consisting primarily of vermiculite, such as No. 13 through No. 19 used in this study, tend to fall apart when the plug is removed from the container.

For Bonneville saltbush, a medium of 50 percent moss peat, 30 percent arcillite aggregate, and 20 percent vermiculite is a useful basic growing medium. Such a medium may be satisfactory for other plant species native to alkaline soils of semiarid areas.

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Songbird Populations and Clearcut Harvesting of Aspen in Northern Utah[1]

Norbert V. DeByle[2]

ABSTRACT

Songbird populations on 10 acres of aspen forest 'ere censused during early summer for 2 years prior nd for 2 years after clearcutting more than half of the ensus area. Numbers of breeding pairs, by species, 'ere estimated. Some 33 bird species were observed. etween 21 and 26 species were seen each year, with 12) 19 of them nesting. Temporary change in habitat was nplicated in the decline or loss of five species and the :crease or invasion of three others.

EYWORDS: *Populus tremuloides*, avifauna, forest harvesting effects, wildlife habitat, breeding birds

The aspen type in the mountainous West is especially aluable for wildlife habitat. It contains an abundant nd diverse avian population, sometimes greater than ny of the vegetation types with which it is associated Vinternitz 1976). Aspen on most sites is seral, and if ven protection from fire or other catastrophic dis-rbance it will eventually be replaced by coniferous rests (Baker 1925; Fowells 1965). Thus, to manage nd perpetuate the type, a disturbance, such as fire or earcutting, is required. After such disturbance, the aspen abundantly regenerates with rapidly growing root suckers (DeByle 1976). Clearcutting has been practiced for decades in eastern aspen forests but not in the West, where other tree species have been the chief source of wood products (Wengert 1976).

Clearcutting a forest quickly removes all the overstory habitat and cover, causes considerable mechanical disturbance to the understory and ground surface, adds logging debris to the surface, and provides an open site that may, if conditions are favorable, become quickly revegetated with abundant herbaceous and woody species. All of these have a profound effect on wildlife habitat, especially that of small creatures dependent upon a narrow niche and relatively small range, such as deciduous forest tree crowns on less than a hectare.

More intensive forest management is certain to occur in the future, and a need exists today to apply treatments for perpetuating aspen on sites rapidly succeeding to conifers. In response to these facts, research on the effects of aspen clearcutting was conducted in a pair of small watersheds in northern Utah. The effects on flora, fauna, streamflow quantity and quality, and nutrient dynamics all were assessed. The effects on songbird populations in the treated watershed, reported here, were a part of the research.

[1] The professional help of Janet L. Young of Utah State University is preciated. She selected the specific census area, made all of the bird servations, and submitted four reports of census data. The presenta-n and interpretation of these data are solely those of the author.

[2] Plant ecologist stationed at the Forestry Sciences Laboratory, gan, Utah 84321.

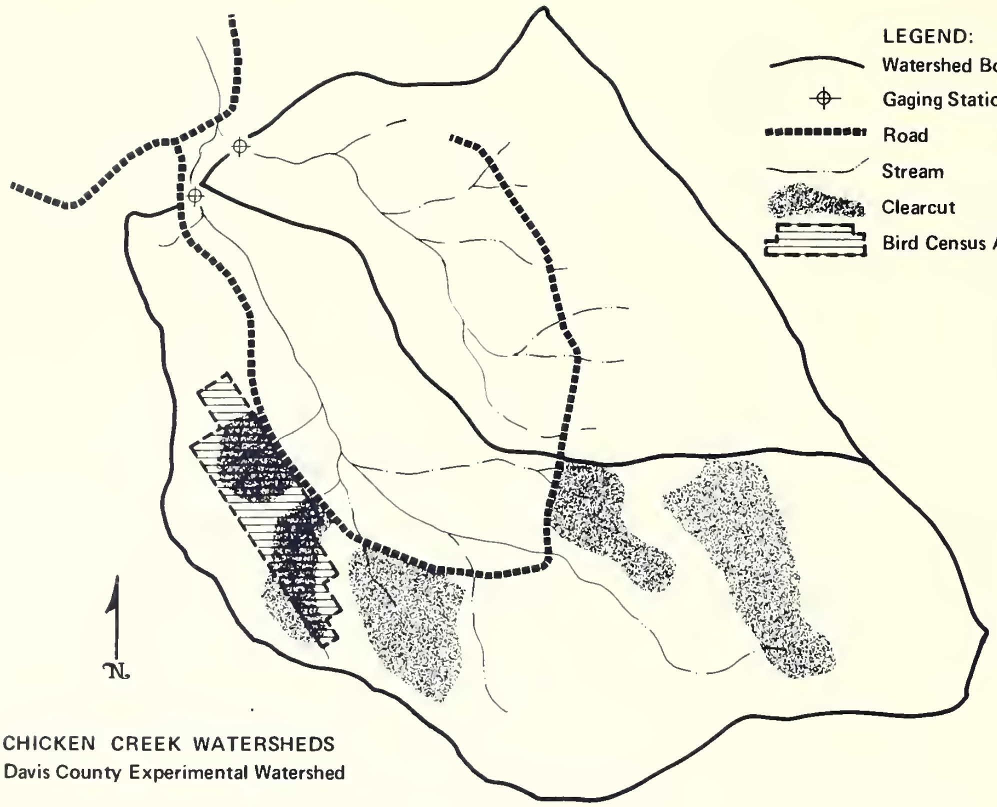

Figure 1.—Map of study area and aspen clearcut units.

SITE DESCRIPTIONS AND METHODS

The watersheds of the East and West Branches of Chicken Creek, at the headwaters of Farmington Creek, about 5 miles (8 km) east of Farmington, Utah, were used for this research (fig. 1). These watersheds encompass 354 acres (143 ha), almost two-thirds of which are covered with aspen forest (Johnston and Doty 1972). The remaining third is covered, in decreasing order of importance, with grass-forb, mountain brush, sagebrush, conifers, and wet meadow vegetation types.

The bird census grid was located on a 24 percent northeast-facing slope at 7,700 feet (2 347 m) elevation in the West Branch drainage. Virtually all of this 10-acre (4-ha) grid was covered with aspen forest. Immediately east of it, an expanse of grass-forb type extends to the stream approximately 75 yards (70 m) away (fig. 2). The aspen on this site averaged 35 years old, with some larger stems in the 80-year-old class (fig. 3). The overstory was about 45 feet (14 m) tall, with an average diameter of 8.4 inches (21 cm). Smaller aspen in the understory made up 70 percent of total tree numbers; they averaged 2 inches (5 cm) diameter and 18 feet (5.5 m) tall. Basal area was 105 square feet per acre (24 m^2/ha). In 1973 approximately 6 percent of the standing trees greater than 4 inches (10 cm) diameter were dead. Very few shrubs were in the understory on the northwest end of the grid, where grasses and abundant forbs yielded about 950 lb/acre (1 065 kg/ha) annual pro duction. A low, brushy understory of snowberr (*Symphoricarpos oreophilus*) was more predominant o the southeast portion.

Between 1974 and 1976, some 30 acres (12 ha) o aspen were clearcut from the West Branch drainag This represents 14 percent of the total area or 2 percent of the aspen acreage on the West Branc Cutting units varied from 3 to 10 acres (1.2 to 4 ha). Tw of the smaller units totaling 6.15 acres (2.5 ha) ar largely within the bird census grid (figs. 1 and 2). Thu about half of the census grid was cut. Cutting con menced after the 1974 bird census, and was large completed by that autumn. All stems greater than inches (5 cm) diameter were felled. Skidding and r moval of all material greater than 3 inches (7.6 cr diameter also was mostly completed on the northwe unit but was only accomplished on the lower third of th southeast unit by the 1975 bird census. All loggir was completed in 1976. There was no treatment of th logging debris; limbs and tops were left broadca throughout the clearcut areas.

The bird census grid was established in June 197 Corners of each quarter-acre were marked. The territo mapping method of Williams (1936) was used to dete mine distribution and number of birds on the are Positions and movements of all birds were recorded c

Figure 2.—View southwest into the north one-half of the bird census area during the first season after clearcutting the unit in center of photo. Stream bottom and meadow in foreground.

gure 3.—Aspen forest on bird census area prior to clearcutting. Photographed in early June, prior to development of lush herbaceous understory.

a map as the observer walked slowly along the grid lines. Estimates of the number of breeding pairs of each species were made from occurrence patterns, nest locations, and simultaneous singing of two or more males. At least five early-morning censuses were made during 2 to 3 weeks in each of 4 years. The period selected annually was based upon prior observation of snowmelt, vegetation development, and bird activity. Each year, the period that coincided with peak territory establishment and nesting activity was chosen. These were June 21 to July 6, 1973; June 13-21, 1974; July 3-22, 1975, a year with an especially deep snowpack and late spring; and June 9-29, 1977.

This study is indicative, not definitive, of the changes in breeding bird populations that may occur when patches are clearcut in a western aspen forest. Weakening the study and preventing statistical analysis of the results are the lack of a census grid on a nearby undisturbed control area, the small size of the existing grid that severely limited the numbers of most bird species, and only 4 years of record with only 1 year of good posttreatment data.

RESULTS

A list of all species observed during the study and their status during each year are presented in table 1. Some 33 bird species visited or bred on this area in the spring and summer of the 4 years of record. Between 21 and 26 species were observed each year, with 12 to 19 of them nesting on or near the site. Some, such as the pine siskin, were consistent visitors; others, such as the broad-tailed hummingbird and flicker, were consistent breeders; and others, such as the blue grouse and nighthawk, were seen during only 1 of the 4 years.

Habitat changes by clearcutting no doubt affected some species. However, the design and extent of this study severely limit assessment of the clearcutting treatment on breeding bird populations. Some changes, nevertheless, are implied. One change: song sparrows were not seen or heard during the two pretreatment years, but were visitors during both 1975 and 1977. Another change: mountain bluebirds and lazuli buntings, though visitors before cutting, established nests on the grid during both years after harvest (fig. 4). In contrast, a pair of hermit thrushes nested in the uncut forest during the two summers before cutting but disappeared afterwards.

Many nesting species occurred as single pairs on the 10-acre grid. Only a few were represented by more than two pairs in any given year. In 1973 and 1974 these more numerous species were house wren, robin,

Table 1.—Species list of breeding and visiting birds observed each year

Species	Status[1] 1973	1974	1975	1977
Blue grouse *(Dendragapus obscurus)*	—	—	V	—
Mourning dove *(Zenaidura macroura)*	V	V	B	—
Great horned owl *(Bubo virginianus)*	V	V	—	V
Common nighthawk *(Chordeiles minor)*	—	V	—	—
Broad-tailed hummingbird *(Selasphorus platycercus)*	B	B	B	B
Rufous hummingbird *(S. rufus)*	—	—	V	—
Common flicker *(Colaptes auratus cafer)*	B	B	B	B
Yellow-bellied sapsucker *(Sphyrapicus varius)*	V	—	B	V
Hairy woodpecker *(Picoides villosus)*	V	—	B	—
Downy woodpecker *(P. pubescens)*	—	—	B	V
Flycatcher *(Empidonax* sp.)	B	B	B	—
Western wood pewee *(Contopus sordidulus)*	B	B	B	V
Tree swallow *(Iridoprocne bicolor)*	V	B	B	B
Black-capped chickadee *(Parus atricapillus)*	V	B	—	V
Mountain chickadee *(P. gambeli)*	—	—	V	—
House wren *(Troglodytes aedon)*	B	B	B	B
American robin *(Turdus migratorius)*	B	B	B	B
Hermit thrush *(Hylocichla guttata)*	B	B	—	—
Swainson's thrush *(H. ustulata)*	B	B	—	B
Mountain bluebird *(Sialia currucoides)*	V	V	B	B
Warbling vireo *(Vireo gilvus)*	B	B	B	B
Orange-crowned warbler *(Vermivora celata)*	—	V	—	—
Yellow-rumped warbler *(Dendroica coronata auduboni)*	B	B	B	B
MacGillivray's warbler *(Oporornis tolmiei)*	B	—	—	B
Black-headed grosbeak *(Pheucticus melanocephalus)*	V	V	V	V
Lazuli bunting *(Passerina amoena)*	—	V	B	B
Cassin's finch *(Carpodacus cassinii)*	—	V	B	—
Pine siskin *(Spinus pinus)*	V	V	V	V
Green-tailed towhee *(Chlorura chlorura)*	V	B	V	—
Gray-headed junco *(Junco caniceps)*	B	B	B	B
Chipping sparrow *(Spizella passerina)*	—	—	B	V
White-crowned sparrow *(Zonotrichia leucophrys)*	V	—	B	—
Song sparrow *(Melospiza melodia)*	—	—	V	V
SUMMARY				
Breeding:	12	14	19	12
Visitors:	11	9	7	9
Total	23	23	26	21

[1]B = breeding, V = visitor, — = not observed.

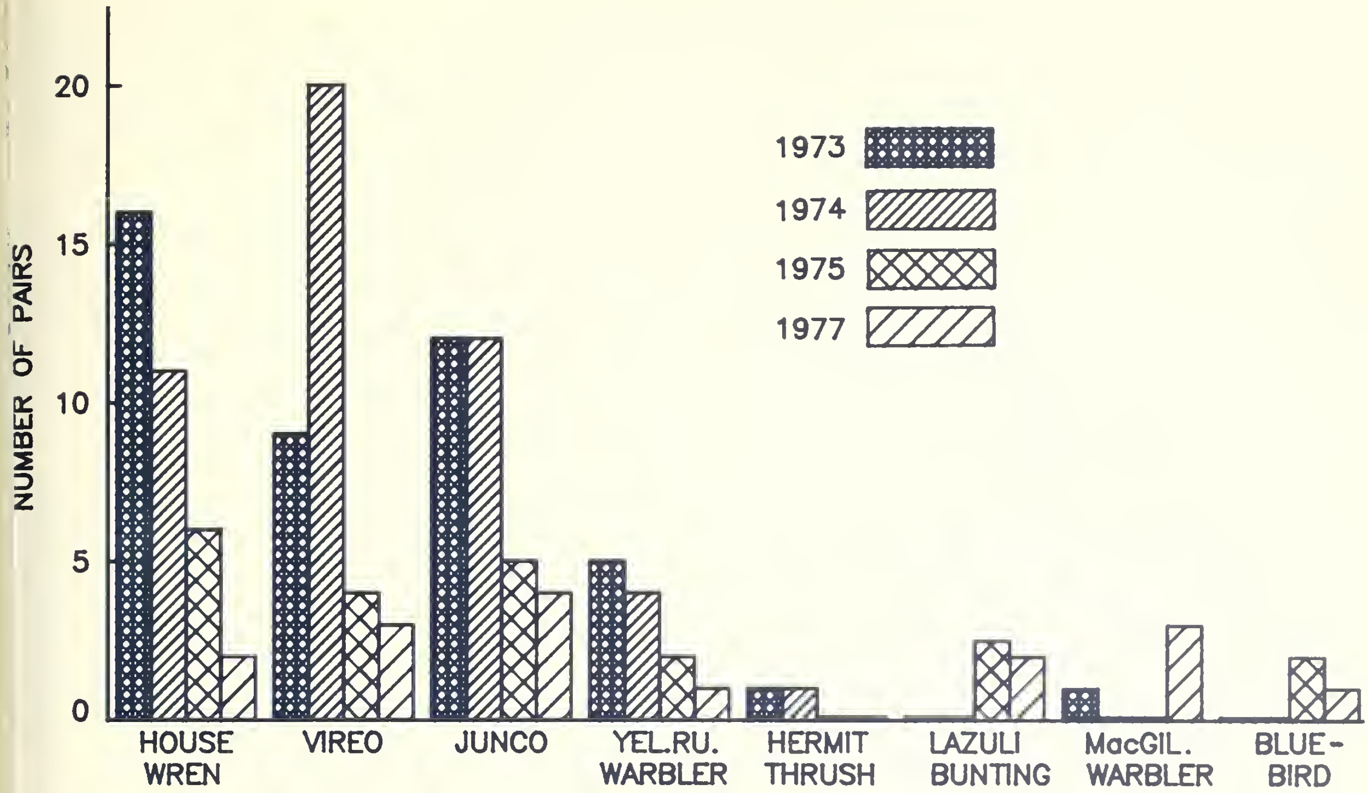

Figure 4.—Breeding pairs of selected bird species (house wren, warbling vireo, gray-headed junco, yellow-rumped warbler, hermit thrush, lazuli bunting, MacGillivray's warbler, and mountain bluebird) estimated from observations during 2 years prior to clearcutting (1973 and 1974) and two years after (1975 and 1977).

/arbling vireo, yellow-rumped warbler, and gray-eaded junco. In 1975 there were only two pairs of ellow-rumped warblers, but in that year the common icker, western wood pewee, and lazuli bunting were dded to the list. In 1977 only three species were umerous, with three pairs each of warbling vireos and ΛacGillivray's warblers, and four pairs of gray-headed ıncos. There were in all 54 pairs of breeding birds on ıe 10-acre area in 1973, 65 in 1974, 44 in 1975, and 2 in 1977. Due to the small size of this census area, ensities of individual species of birds per unit area annot be satisfactorily estimated from these data.

The presence or absence of one or two pairs of any pecies in any given year could be attributed as much to hance as to any habitat change. But if the population hange was consistent with the habitat alteration after ıe 1974 census, or if the species was numerous, it was ıcluded in figure 4. The three most common species efore cutting (house wren, warbling vireo, and gray-eaded junco) all declined markedly after treatment. ellow-rumped warbler, though never abundant, de-reased to one-third of its pretreatment population. learcutting may have been the cause of the decline or loss of five species of breeding birds and the increase or invasion of three species.

The species cluster maps for 1977 indicate that the flicker, junco, warbling vireo, yellow-rumped warbler, Swainson's thrush, western wood pewee, and chickadee all preferred the aspen forest. The MacGillivray's warbler, chipping sparrow, and song sparrow were partial to the clearcut areas. The bluebird, lazuli bunting, house wren, tree swallow, pine siskin, yellow-bellied sapsucker, and black-headed grosbeak seemed to concentrate along the edges.

DISCUSSION

Knowledge of habitat preferences for each of the species apparently affected by clearcutting lends credence to these observations. House wrens and mountain bluebirds are both cavity nesters. The wren population declined, perhaps because nesting habitat was destroyed and foraging habitat (insects in the foliage) also was partially removed. The bluebird belongs to a ground-insect feeding guild (Salt 1953) and prefers open brushy areas for foraging. Clearcutting small patches provided more open habitat adjacent to the uncut aspen forest, thus improving habitat for bluebird feeding while apparently retaining sufficient cavities for nesting. The warbling vireo prefers the aspen forest (Winternitz 1976), nests in trees, and is a foliage-insect feeder. Clearcutting removed both nesting and foraging habitat for vireos; the population declined. The gray-headed junco prefers the aspen forest (Winternitz 1976); after cutting, junco numbers declined. The yellow-rumped warbler is partial to conifer forests (Salt 1957; Peterson 1961) and is a foliage-insect feeder. Cutting removed foraging habitat for this species. In contrast, MacGillivray's warbler prefers a well-developed foliage cover less than 25 feet (8 m) high for foraging (Ramsden and others 1979) and nests in low bushes or weeds (Peterson 1961). Clearcutting increased this habitat.

In spring 1975 the snowpack was excessively deep in the mountains of northern Utah. Its melt and disappearance that year was delayed about 5 weeks, with much of the study area not clear of snow until early July. The aspen was leafed out in advance of snow disappearance. With these conditions, phenology of plants previously buried in the snow becomes compressed in time, with very rapid growth and development occurring immediately after exposure. Nesting habitat in 1975 was temporarily altered. Furthermore, melt at higher elevations was even later, keeping many bird species below 9,000 feet (2 743 m) until late July.

This leads to speculation about the effects of delayed snowmelt on birds visiting or breeding in the aspen type in Chicken Creek. Perhaps there was feverish nesting activity by all species as soon as the site opened up. Perhaps some species moved to more favorable sites upon finding Chicken Creek snow covered in June. Perhaps some birds, which would normally nest at higher elevations, used the Chicken Creek site. In any event, there were 19 species breeding on the study area in 1975, almost half again as many as in the other 3 years. This was the only year in which the mourning dove, yellow-bellied sapsucker, hairy and downy woodpeckers, chipping and white-crowned sparrows, and Cassin's finch were represented in the breeding population.

Clearcutting was essentially completed by 1975, but more than half of the southeast unit remained covered with felled aspen trees that had not been limbed or bucked. All of this down material presented a unique habitat on this unit, which added to the unusual 1975 conditions. This may have encouraged visits or nesting by species partial to a dead, deciduous brushy habitat.

The mosaic of vegetation types on Chicken Creek and the proximity of the aspen clearcut units to other types no doubt influenced the bird populations. Opening this aspen forest by clearcutting did not provide a totally unique and new habitat on the area; instead, it enlarged the amount of open, brushy habitat in the watershed. The forest "edge effect" was present on or immediately adjacent to the 10-acre census grid both before and after treatment. Clearcutting the two censused units expanded the amount of edge by approximately 2,000 feet (610 m).

Clearcutting, particularly in the aspen forest, is a temporary alteration of habitat. Within 30 years an aspen forest should again occupy these harvested units. The herbaceous and low brushy stages of succession persist for only 1 or 2 decades, after which aspen saplings will dominate (DeByle 1976). Clearcutting aspen in small blocks on, say, an 80-year rotation will provide a mosaic of age and size classes, will increase "edge," and should increase bird species diversity and perhaps total numbers as well. This remains to be proven with more definitive studies in the managed aspen forest.

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**Intermountain
Forest and Range
Experiment Station**

Research Note
INT-303

February 1981

SURVIVAL AND HEIGHT GROWTH OF COASTAL AND INTERIOR WESTERN WHITE PINE SAPLINGS IN NORTH IDAHO

R. J. Steinhoff[1]

ABSTRACT

Western white pine saplings from the Olympic Penin-ula of Washington and from north Idaho sources lanted together in north Idaho did not differ in their urvival rates. There has been no visual evidence of reezing injury to either group. At age 12, height of the oastal saplings generally falls within the height range or north Idaho saplings. The findings lend support to arlier results, which indicated that most of the variation n north Idaho white pines is found within, rather than etween, populations.

EYWORDS: *Pinus monticola,* geographic variation, provenance trials.

Several tests have been established to study adapt-bility and variation in the north Idaho portion of the terior range of western white pine *(Pinus monticola* ougl.), but there has been no rangewide study of the pecies. Within north Idaho we have found white pine roadly adaptable with little variation among young ees that can be related to elevation or latitude of seed ollection (Steinhoff 1979; Rehfeldt 1980). Seedlings om northwestern Washington were tested for survival northern Idaho and to compare growth rates with cal seedlings. In this research note I present and ompare survival and height data for a 12-year-old test western white pine saplings from northwestern ashington and northern Idaho.

MATERIALS AND METHODS

The north Idaho seed was collected from five trees in ach of 45 collection areas, from approximately 46° to 9° N. latitude and from 455 m to 1 585 m elevation. The oastal seed came from the east and west sides of the lympic Peninsula. The collection from the west side onsisted of seed from five trees growing at an elevation approximately 160 m near Humptulips, Wash., in an ea referred to as the "Promised Land." On the east de of the Peninsula, the seed was collected from five ees growing at elevations ranging from 350 to 600 m the Olympic National Forest near Shelton, Wash.

The coastal seed was added when the tests were underway and therefore received only 40 days of stratification as compared to 100 days for the north Idaho seed. As a result of the shorter stratification period, fewer of the coastal seeds germinated and some did not germinate until the second year. Nevertheless, because of records kept on germination time and our culling practices, I believe the data reported here offer a valid comparison.

Seed from both the "Promised Land" and Olympic National Forest collections were included along with all 45 north Idaho collections in a replicated nursery trial. Seedlings in the test were grown for 3 years in 10-tree row plots at a spacing of 5 x 10 cm in a 1:1:1 mix of sand, forest soil, and peat moss. Two replicates from that test were outplanted to a plot called Ida Creek at the Priest River Experimental Forest (PREF) in north Idaho at an elevation of 790 m. Seedlings from the other two replicates were outplanted to a different plot where they were killed by pocket gophers. At Ida Creek, the seedlings were planted in two replicates, with 5 seedlings from each family in a stand planted together in a row 25 seedlings long. Spacing was 1.2 x 1.2 m.

In a second part of the test, seed from only the "Promised Land" and 24 of the north Idaho collections was broadcast sown in native soil in the same nursery at Moscow, Idaho. Seedlings from that planting were transplanted to a series of six field plantations. Data from the low and high plantations at PREF are reported here. The other plantations have been plagued with mortality problems resulting from inadequate site preparation and early infection by white pine blister rust *(Cronartium ribicola).* In this phase of the test, seedlings from the individual families in a stand were mixed and planted together in 10-tree row plots replicated five times. Further details of seed collection and nursery practices as well as early growth data for the north Idaho

[1] Research geneticist located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho. Seed for tests supplied by the Industrial Forestry Association and the Olympic National Forest. Dr. Burton Barnes, now at the University of Michigan, solicited the nonlocal seed and personally collected much of the north Idaho seed.

seedlings have been reported earlier (Steinhoff 1979). The saplings are now 12 years old and have been in the plantations for 9 years.

RESULTS

In all the plantations, survival of the coastal saplings fell within the range of survival values for saplings of the north Idaho collections (table 1). To date ther has been no visual evidence of spring or fall frost damage or differential winter freezing injury among any of the populations of saplings even though there have beer two severe winters. In contrast, during the winter o 1972-73, nearly all of the coastal Douglas-fir *(Pseudot suga menziesii* [Mirb.] Franco) seedlings were killed while interior seedlings suffered much less mortalit and injury in a nursery test 2 km away at approximatel the same elevation as the Ida Creek plantation (Reh feldt 1977).

Table 1.—Survival and height of coastal and north Idaho white pine saplings at age 12 years

Seed source		Ida Creek[1]		PREF Low[1]		PREF High[2]	
		Survival	Height	Survival	Height	Survival	Height
		Percent	*Meters*	*Percent*	*Meters*	*Percent*	*Meters*
Olympic National Forest[3]		96	2.62				
Promised Land[4]		94	2.39	88	1.63[5]	62	1.45
North Idaho	$\bar{x}$	95[6]	2.49	84[7]	1.92[5]	74[7]	1.52
	Range	88-100	2.22-2.75	66-92	1.75-2.27	60-86	1.37-1.68

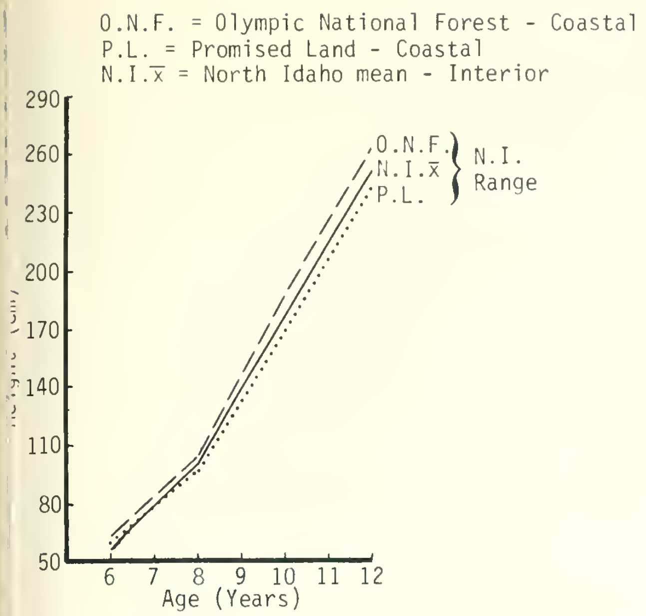
[1]Adjacent plantations at the Priest Experimental Forest - latitude 48° 21' N. Elevation 790 m.
[2]Plantation elevation 1 400 m.
[3]East side, Olympic Peninsula near Shelton, Wash., elevation 350-600 m.
[4]West side, Olympic Peninsula, near Humptulips, Wash., elevation approx. 160 m.
[5]Significantly different at 1 percent level
[6]Mean of collections from 45 stands from 46° to 49°, N. latitude, elevation 455 to 1 585 m.
[7]Mean of collections from 24 stands.

Height of the coastal saplings also was within the range of values for north Idaho saplings in two of the three plantations (table 1 and fig. 1). In the low PREF plantation, the height of the "Promised Land" saplings was significantly less than the average for the north Idaho saplings. For the other plantations, there were no significant differences between the means for coastal and north Idaho saplings. The substantial difference between the means for the Ida Creek and PREF low plantations are primarily the result of different nursery growing conditions, i.e., spaced planting in a soil:sand: peat moss mix versus dense broadcast sowing in a heavy clay soil respectively which resulted in sizable initial differences in size and condition of the two groups of seedlings.

DISCUSSION AND CONCLUSIONS

Although the number of collections of coastal white pine is too small to draw broad conclusions, the initial impression is that saplings of coastal white pine sources differ little from those of interior sources whe grown in north Idaho. In another small plantation c Vancouver Island, B.C., 7-year old seedlings originatir from north Idaho seed were taller than local seedlin but not significantly so, i.e., 56 versus 47 cm respective (personal communication from R. C. Bower, MacMill Bloedel Ltd.). Hunt and von Rudloff (1977) also four that no obvious differences between coastal and i terior populations could be detected by comparing le oil-terpene percentages. In their study, within popul tion variation was generally much higher than th between different populations. All of these results le support to our earlier findings that within populatic variation is generally higher than that between popul tions with regard to height growth for north Idaho whi pine.

The results with western white pine contrast marke with growth differences between coastal and interi forms of Douglas-fir and grand fir *(Abies grandis* [Dou Lindl). In Idaho tests, the few coastal Douglas-



igure 1.—Growth of coastal and north Idaho white pines from age 6 to age 12 at Ida Creek.

ɜedlings that survived to age 4 were about 60 percent .ller than those from the interior (Rehfeldt 1977) but ıey did not survive the winter cold once they were taller ıan the protective snow cover. In coastal trials, the ɔastal trees are also much faster growing than interior ɪes (Haddock and others 1967). Seedlings from a ngle coastal grand fir population tested in north Idaho ere 50 percent taller than interior seedlings at age 4 ıteinhoff 1980). During one winter, both coastal and terior seedlings that were not protected by snow had ost of their exposed foliage and some buds killed, but l seedlings survived. Nevertheless, preliminary artifi- al freezing tests have indicated that the coastal ɜedlings are injured at warmer temperatures than terior ones. In trials in Oregon (Douglas 1974), coastal and fir seedlings also were faster growing than in- rior ones. Thus, in north Idaho tests among similar ɜographic samples of these three species, young ɔastal and interior western white pine trees grow at ɔout the same rate and all appear completely cold hardy; young coastal grand fir trees grow faster than interior ones but are more easily damaged by cold temperatures; and coastal Douglas-fir seedlings are faster growing than interior ones but are not cold hardy.

Test results indicate no potential for increasing the growth of interior western white pine by introducing genes from coastal populations. Conversely, there would be no growth loss if interior trees or genes from them were used in coastal programs. Because of the equality of growth rates and the apparent cold hardiness of coastal trees, the transfer of genes for other traits, such as blister rust resistance, might be made from coast to interior breeding programs, or vice versa, through a simple one-step hybridization process.

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Forest Floor Fuel Loads, Depths, and Bulk Densities in Four Interior Alaskan Cover Types

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ABSTRACT

Forest floor fuel loads, depths, and bulk densities are ported for four Interior Alaska cover types. Cover types cluded are upland black spruce, lowland black spruce, hite spruce, and paper birch. Results indicate forest ɔor depths range from slightly over 2 inches to about 7 ches for all areas sampled. Loads range from 2.1 lb/ft^2 3.4 lb/ft^2 (10.25 kg/m^2 to 16.60 kg/m^2), while bulk ɛnsities ranged from 4.9 lb/ft^3 to 10.6 lb/ft^3 (78.50 ı/m^3 to 169.81 kg/m^3). Study results compare favorably th similar work in other locations.

EYWORDS: fuels, fuel loads, fuel depths, fuel bulk densities, Alaska

The forest floor has an important influence on the drologic characteristics of a site. Amount of organic ıaterial, its depth, and bulk densitites are fundamental i describing forest soil characteristics. The forest floor i also a very important fuel component which influ- ces ignition and subsequent fire behavior. The forest for is generally defined as the accumulated organic ıatter above mineral soil. This matter consists of three l/ers: the L layer, consisting of unaltered organic ıatter; the F layer, consisting of partly decomposed ıatter; and the H layer, consisting of well decomposed ıatter.

nformation regarding the forest floor is absolutely r cessary in evaluating the effects of fire, either wildfire c prescribed fire. The intensity and duration of a fire is r ated to the fuels and fuel moisture, and the forest f or is an important component. The depth of material and the depth of burn can affect the amount of sub-surface killing of plant parts; so we must know more about this portion of the system.

Since the development of fire behavior models (Rothermel 1972) and their subsequent sophistication, fire researchers and fire managers alike have become more interested in the characteristics of forest vegetation. Improvements in and concern for forest fuel inventories, changes in fire management policies, fire use, and computerization have all contributed to the need for more and better information regarding forest and range biomass as a fuel. This note reports some of the information needed by those utilizing fuel data with today's technology to better predict possible outcomes of various management strategies and the impact of fire.

METHODS

Four sampling sites were selected that represent cover types commonly visited by fire in Interior Alaska. The characteristics of each sample site are detailed in table 1 (for SI unit table, see appendix table 7). These sites are all within the Fairbanks vicinity. The specific site location is the Bonanza Creek Experimental Forest, latitude 64°45' N. and longitude 148°15' W.

The dominant representative ground fuel (moss or leaf litter) in each general cover type was considered for sampling. An effort was made to take as uniform and representative a fuel sample as possible. The reader is cautioned to remember that this study was a localized sample and may not represent Interior Alaska as a

[1]Team Leader in the Fire Control Technology Project at the Northern Forest Fire Laboratory, Missoula, Mont., but conducted the study while ›oject Leader at the Institute of Northern Forestry, Fairbanks, Alaska; Research Supervisor, and Research Meteorologist, respectively, Systems for ıvironmental Management.

Table 1.—Sample stand characteristics

Dominant overstory species	Elevation	Topography	Aspect	Slope	Soils	Permafrost	Density	Dominant overstory species Basal area	Age	Height	Mean d.b.h.
	Feet			*Percent*			*Stems/acre*	*Ft²/acre*	*Years*	*Feet*	*Inches*
Birch (*Betula papyrifera* Marsh.)	1,550	Slope	S	10-20	Ester Silt loam	Intermittent	303	10	110-130	55	8.0
Upland black spruce (*Picea mariana Mill.*)	1,155	Spur ridge	S	0-10	Ester Silt loam	Intermittent	2,000	149	101	33	3.7
Lowland black spruce (*Picea mariana* Mill.)	550	Flat		0	Alluvial Tanana Silt loam	Present	11,067	82	51	9	1.05 d.g.h.1
White spruce (*Picea glauca* [Moench] Voss)	575	Rolling	S	0-10	Ester Silt loam	Intermittent	425	118	62	67	6.8

[1]d g h = diameter ground height or basal diameter.

whole. Within-site and between-site differences indicate that variability is common and rather larger in some instances. Samples were dried to a constant weight in order of collection at 217° F (103° C).

Samples 1 ft² (0.09 m²) were taken down to mineral soil. In areas with mosses as the predominant vegetation, as in the spruce stand, samples were stratified as follows:

1. Green moss, dead moss, or the litter layer (L) and the fermentation layer (F).
2. Humus layer (H) down to, but not including, the mineral soil.

At the time of sampling, the depth of each layer was recorded to the nearest one-half inch (1.25 cm). Small herbs and shrubs growing within the sample were included, the top material being combined with the L and F layers. Large material, such as limbs, was removed. In the birch type, the litter (L) and humus (H) layers were combined. These layers were not separated because of the difficulty of doing so throughout the season. The F layer was often indistinct and the L layer was sometimes very shallow. Three 1-ft² (0.09-m²) samples were taken at each site, including all material down to, but not including, mineral soil at each sampling time. A total of 114-120 samples were taken over a period of 4 summers. Sample numbers differed between cover types. The sample sites were visited from 10-14 times each summer for the period of the study.

RESULTS

Sample statistics for forest floor depths, loads, and bulk densities are summarized in table 2 (for SI unit table, see appendix table 8) by forest cover type and forest floor layer.

Total forest floor depth (litter plus humus layers) averaged about 4 inches (10 cm) in the birch and white spruce stands and was slightly over 6.5 inches (16.5 cm) in the upland and lowland black spruce stands. Standard deviations of litter and humus depths ranged from 30 to 40 percent of the means while standard errors were quite low, 3 to 4 percent. Within each cover type, the litter and humus layers appeared to have approximately equal depths. The fuel loads of the humus layers, on the other hand, were from two to four times greater than those of the litter layers within each cover type. Litter loads ranged from 0.51 to 0.75 lb/ft² (2.49 to 3.66 kg/m²), and humus loads ranged from 1.62 to 2.34 lb/ft² (7.91 to 11.42 kg/m²). The standard deviations for loads ranged from 39 to 80 percent, exhibiting greater variability than forest floor depths even though the standard errors remained quite low (4 to 7 percent of the means).

The difference between litter and humus layer loads is manifested in the bulk densities of the two layers. Humus bulk densities were two to three times greater than those of the corresponding litter layer. Litter bulk densities averaged 3.2 lb/ft³ (51.3 kg/m³) for all three spruce stands while humus bulk densities ranged from 6.9 to 9.1 lb/ft³ (111 to 146 kg/m³). Bulk density standard deviations ranged from 38 to 108 percent of the mean, showing still greater variability than either forest floor depth or load. Standard errors of the mean remained low at 4 to 10 percent.

The results in table 2 suggest the possibility that forest floor depth, load, and bulk density did not vary significantly between the upland black spruce, lowland black spruce, and white spruce stands for the litter or humus layers. An analysis of variance was conducted to test the hypothesis that forest floor depth, load, and bulk density were the same for the three cover types. Significant differences ($p < 0.05$) between cover types were found only in the litter and humus layer bulk densities (table 3). A Scheffé multiple mean comparison test showed litter bulk densities to be alike for all three spruce types at $p < 0.05$. The same test differentiated two cover type groups for humus layer bulk density; lowland black spruce, and upland black spruce—white spruce.

Table 2.—Litter and humas layer depths, loads, and bulk densities for four Alaskan forest cover types

Forest cover type	Layer[1]	Depth			Load			Bulk density			Sample size
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	
		---Inches---			---Lb/ft²---			---Lb/ft³---			
Birch	L + H	4.04	1.46	0.13	3.41	1.55	0.14	10.60	4.78	0.44	119
Upland black spruce	L	2.79	1.08	.10	.64	.28	.03	3.09	1.58	.14	120
	H	3.78	1.67	.15	2.34	1.88	.17	8.91	9.66	.88	120
	L + H	6.75	2.31	.21	2.98	1.91	.17	6.00	4.44	.41	120
Lowland black spruce	L	2.88	1.00	.09	.75	.29	.03	3.24	1.24	16	114
	H	3.62	1.82	.17	1.76	.86	.08	6.91	4.45	.42	114
	L + H	6.50	2.39	.22	2.49	.91	.09	4.94	2.15	.20	114
White spruce	L	2.15	.76	.07	.51	.21	.02	3.27	1.83	.17	117
	H	2.29	.90	.08	1.62	.88	.08	9.14	4.54	.42	116
	L + H	4.43	1.29	.12	2.12	.97	.09	6.12	3.06	.28	117

[1]L = litter layer, H = humas layer, L + H = litter and humus layers

Table 3. — Analysis of variance statistics of forest floor depths, loads, and bulk densities by forest cover type and forest floor layer

Variable	Litter layer[1]		Humus layer[1]		Litter and humus[2]	
	F ratio	(d.f.)	F ratio	(d.f.)	F ratio	(d.f.)
Depth	[3]20.5	(2,348)	[3]34 3	(2,348)	[3]57.1	(3,466)
Load	[3]23.4	(2,354)	[3]10.3	(2,352)	[3]19 1	(3,466)
Bulk density	.47	(2,348)	3.80	(2,346)	[3]52.1	(3,466)

[1]Analysis of variance between upland black spruce, lowland black spruce and white spruce

[2]Analysis of variance between birch, upland black spruce lowland black spruce, and white spruce

[3]p <0 05

The possibility of using forest floor depth to predict layer loads and bulk densities was investigated. The capability deriving litter and humus load and bulk density from depth measurements would greatly expedite fuel sampling in the four cover types.

The correlation coefficients (Pearson's simple r) of litter, humus, and litter-humus depths with their associated loads and bulk densities are presented in table 4. The load and bulk density values were converted using natural logarithm transformations to more closely approximate a normal distribution.

Table 4. — Pearson correlation coefficients of forest floor depth with load and bulk density by forest cover type and forest floor layer

Forest cover type	Layer[1]	Forest floor depth correlation coefficient with:		
		ln (load)	ln (bulk density)	n
Birch	L + H	[2]0 497	[2]−0.243	119
Upland black spruce	L	.279	[2]− .492	120
	H	[2] .313	[2]− .522	120
	L + H	.190	[2]− 526	120
Lowland black spruce	L	[2] .471	[2]− .424	114
	H	[2] .362	[2]− .503	113
	L + H	[2] .339	[2]− .452	114
White spruce	L	.047	[2]− .692	117
	H	[2] .351	[2]− 403	116
	L + H	.157	[2]− 458	117

[1]L = litter layer, H = humus layer, L + H = litter and humus layers

[2]p <0 01

The correlation between depth and load was modest, but statistically significant, for all cover types and layers except the white spruce litter layer and the white and lowland black spruce litter-humus layers. The correlation between depth and bulk density was significant ($p < 0.05$), but moderate, for all cover types and layers. The depth correlations with bulk densities tended to be better than those for depth with load. This is not unexpected since depth is one of the factors determining bulk density.

Finally, linear regressions were determined between the litter and humus layer depths and their associated natural logarithm transforms of load and bulk density. The forms of the equations are:

$$\ln(Y) = \alpha + \beta X + e \text{ where}$$

Y = dependent variable

α = intercept

β = slope

X = layer depth (inches)

e = regression error.

For loads, Y and α have units of lb/ft², and for bulk densities, Y and α have units of lb/ft³.

Again, the linear relationships between depths and loads and between depths and bulk densities are significant but too weak to be useful for prediction purposes (table 5). Only the three depth-load regressions for spruce litter-humus layers have insignificant slopes ($p < 0.05$). In only one instance does the simple linear regression account for more than 30 percent of the variance in the data.

Table 5. — Regression statistics for forest floor load and bulk density as a function of depth by forest cover type and forest floor layer

Forest cover type	Layer[1]	*ln* (load) = $\alpha + \beta$ (depth)					*ln* (bulk density) = $\alpha + \beta$ (depth)				
		Intercept	Slope	r^2	SEE	n	Intercept	Slope	r^2	SEE	n
Birch	L + H	[2]-0.363	[2]0.183	[2]0.25	0.468	119	[2]2.657	-0.076	[2]0.06	0.443	119
Upland black spruce	L	- .839	[2] .112	[2] .08	.419	120	[2]1.641	- .225	[2] .25	.427	119
	H	[2] .344	[2] .096	[2] .10	.490	120	[2]2.653	- .181	[2] .27	.497	120
	L + H	[2] .819	.027	.01	.407	114	[2]2.544	- .138	[2] .27	.403	114
Lowland black spruce	L	[2]- .880	[2] .176	.22	.331	114	[2]1.551	- .153	[2] .18	.328	114
	H	.063	[2] 104	.13	.487	113	[2]2.351	- .163	[2] .25	.510	113
	L + H	[2] 429	.064	[2] .07	.379	107	[2]2.165	- .104	[2] .17	.383	107
White spruce	L	[2]- .695	-.024	.00	.393	117	[2]2.085	- 485	[2] .48	.388	116
	H	- .096	[2] .198	[2] .12	.478	116	[2]2.616	- 230	[2] .16	.472	116
	L + H	[2] .430	.052	.03	.425	117	[2]2.506	- 178	[2] .26	.389	116

[1]L = litter layer, H = humus layer, L + H = litter and humus layers

[2]$p < 0.01$

SUMMARY AND CONCLUSIONS

Individual litter and humus layer depths are similar in the four Alaskan cover types studied. Mean total (litter plus humus) depths averaged about 4 inches (10 cm) in birch and white spruce stands, and approximately 6 inches (15 cm) in both upland and lowland black spruce areas. The natural variability of litter and humus layer depths, as expressed by the coefficient of variability (percent), ranged from 31 to 43 for the seven cover type-layer combinations.

The humus layer contained from two to four times as much biomass as did the litter layer. Litter layer loads ranged from 0.51 to 0.75 lb/ft^2 (2.49 to 3.66 kg/m^2) in the white spruce and two black spruce stands. In the same areas, humus layer loads ranged from 1.62 to 2.34 lb/ft^2 (7.91 to 11.42 kg/m^2). The natural within-stand variability of litter and humus loads for the three stands ranged from 52 to 143 percent, while the sample error (standard error) ranged from 4 to 7 percent of the mean.

The humus layer generally has a bulk density two to three times greater than the litter layer. Humus layer bulk densities were on the order of 7 to 10 lb/ft^3 (112 to 160 kg/m^3), while litter layer bulk densities averaged about 3 lb/ft^3 (48 kg/m^3). Within-stand variability ranged from 26 to 58 percent while standard erros were from 4 to 9 percent.

Weak, but generally highly significant relationships, as expressed by Pearson's coefficient of correlation (r), were found between litter or humus layer depths and their associated loads and bulk densities. Linear regressions of litter or humus layer depth (independent variable) with loads and bulk densities (dependent variables) were performed. Again, regressions were generally significant, but accounted for less than 30 percent of the variability in the data. One possible explanation for the weak correlations is that with depth measurements of one-half inch (1.27 cm) increments were too coarse considering the total depth encountered. A more precise measurement could have improved the resulting analysis. Also, extreme variation between samples was encountered which can also help explain part of the problem.

The bulk density data developed in this study compare relatively well with similar data from other areas. The birch data, however, are considerably higher for this study than the data reported by Troth and others (1976) (table 6). Considering the standard deviation, it is, however, within the general range. Comparison with black spruce data shows very close agreement with other values reported in Canada, Michigan, and Alaska. The Canadian black spruce bulk density values range from 2.68 lb/ft^3 to 15.61 lb/ft^3 (0.043 g/cm^3 to 0.25 g/cm^3) whereas the data from this study range from 3.16 lb/ft^3 to 10.25 lb/ft^3 (0.05 g/cm^3 to 0.16 g/cm^3). These data are well within the range of bulk densities reported elsewhere for black spruce. The other bulk density data for species such as white spruce-balsam poplar, ponderosa pine, red pine, jack pine, spruce-fir, and lodgepole pine all appear to have forest floor bulk densities in the same general range.

Practical application of these data will be made in defining forest floor characteristics and water relations as well as moisture response characteristics. Because of the forest floor's importance as a source of fuel for either wildfires or prescribed fires, these data will eventually be used in combination with other fuel properties, such as moisture content, to predict fire behavior and resultant fire effects. Increased understanding of the forest system and its properties as a whole will improve our ability to make better management decisions and application.

Table 6. — A comparison of mean bulk densities from several locations and sources

Source	Layer	Species	Location	Mean bulk density	
				Lb/ft^3	*g/cm*^{3}
Mader (1953)	F,H	White spruce	Ontario		
		Balsam poplar	Ontario	9.99	0.16
	F,H	Black spruce, spruce	Michigan	4.99	.08
	F,H	Black spruce	Ontario	15.61	.25
Brown (1966)	F,H	Red pine	Minnesota	4.32	.069
	F,H	Jack pine	Michigan	6.1	.098
Ffolliott and others (1968)	F	Ponderosa pine	Arizona	1.8	.029
Mader and Lull (1968)	F	White pine	Massachusetts	4.5	.072
	H	White pine	Massachusetts	9.0	.144
Brown (1970)	F,H	Ponderosa pine	Montana	4.74	.076
Kiil (1970)	F,H	Spruce-fir	Alberta	3.75	.06
Golding and Stanton (1972)		Spruce-fir	Alberta	6.24	.10
		Lodgepole pine	Alberta	8.74	.14
Troth and others (1976)	L,F,H	Black aspen	Alaska	3.64	.058
	L,F,H	Black spruce	Alaska	3.25	.052
Viereck and Dyrness (1979)	L,F,H	Black spruce	Alaska	2.68	.043
	L,F,H	Black spruce	Alaska	4.81	.077
	L,F,H	Black spruce	Alaska	8.49	.136

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APPENDIX TABLES

Table 7. — Sample stand characteristics

Dominant overstory species	Elevation	Topography	Aspect	Slope	Soils	Permafrost	Density	Dominant overstory species: Basal area	Age	Height	Mean d.b.h.
	Meters			*Percent*			*Stems/ha*	*m²/ha*	*Years*	*Meters*	*cm*
Birch (*Betula papyrifera* Marsh.)	472.75	Slope	S	10-20	Ester Silt loam	Intermittent	748	2.29	110-130	16.78	20.32
Upland black spruce (*Picea mariana* Mill.)	352.28	Spur ridge	S	0-10	Ester Silt loam	Intermittent	4,942	34.21	101	10.07	9.40
Lowland black spruce (*Picea mariana* Mill.)	167.75	Flat		0	Aluvial Tanana Silt loam	Present	27,346	18.83	51	2.74	2 67 d.g.h [1]
White spruce	175.38	Rolling	S	0-10	Ester	Intermittent	1,050	27.09	62	20.43	17.27

[1]d.g h. = diameter ground height or basal diameter

Table 8. — Litter and humus layer depths, loads, and bulk densities for four Alaskan forest cover types

Forest cover type	Layer[1]	Depth: Mean	Depth: Standard deviation	Depth: Standard error	Load: Mean	Load: Standard deviation	Load: Standard error	Bulk density: Mean	Bulk density: Standard deviation	Bulk density: Standard error	Sample size
		Centimeters			*kg/m²*			*kg/m³*			
Birch	L + H	10.3	3.71	0.33	16.65	7.57	0.68	169.8	76.6	7.0	119
Upland black spruce	L	7.09	2.74	.25	3.12	1.37	.15	49.5	25.3	2.2	120
	H	9.60	4.24	.38	11.42	9.18	.83	142.7	154.8	14.1	120
	L + H	17.15	5.87	.53	14.55	9.33	.83	96.1	71.1	6.6	120
Lowland black spruce	L	7.32	2.54	.23	3.66	1.42	.15	51.9	19.9	2.6	114
	H	9.19	4.62	.43	8.59	4.20	.39	110.7	71.3	6.7	114
	L + H	16.51	6.07	.56	12.16	4.44	.44	79.1	34.4	3.2	114
White spruce	L	5.46	1.93	.18	2.49	1.03	.10	52.4	29.3	2.7	117
	H	5.82	2.29	.20	7.91	4.30	.39	146.4	72.7	6.7	116
	L + H	11.25	3.28	.30	10.35	4.74	.44	98.0	49.0	4.5	117

[1]L = litter layer, H = humus layer, L + H † litter and humus layers.

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**Intermountain
Forest and Range
Experiment Station**

Research Note
INT-305

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Soil Disturbance Caused by Clearcutting and Helicopter Yarding in the Idaho Batholith

James L. Clayton[1]

ABSTRACT

Disturbance to soil from helicopter logging and broadcast burning of slash from a large commercial clearcut in the Idaho batholith was evaluated. Two hundred permanent 10.8 ft² (1 m²) plots were evaluated prior to and for a 2-year period following logging and burning. Measurements included: changes in ground cover, soil horizon mixing, soil erosion, litter layer changes, and slash cover changes. Accelerated erosion was found on 2 percent of the area, and volume estimates indicate a short-term increase of approximately 10 times natural rates. Broadcast burning resulted in litter losses on 14 percent of the treated area. Eroded areas appear to be healing, and these short-term changes in soil conditions are small compared to soil disturbance from other logging systems.

KEYWORDS: soil disturbance, erosion, helicopter logging, Idaho batholith

Coarse-textured granitic soils of the Idaho batholith cause continual concern to land managers because of their high potential for accelerated erosion following disturbance. This is, in part, a result of soil properties, such as low cohesion and poor aggregate stability, and of high climatic stresses associated with frequent high intensity summer rainstorms (Kidd 1964), rapid spring snowmelt, and rain-on-snow events. Following logging and road construction, erosion rates over 750 times normal rates have been reported (Megahan and Kidd 1972).

Damage to the on-site soil and watershed resources coupled with deterioration of downstream values by sediment has had a major impact on land management policy in the Idaho batholith. For example, the 1,300-mi² (3 370 km²) South Fork of the Salmon River watershed was closed to logging and road construction for 11 years from 1966 to 1977 as a result of tremendous inflows of sediment during the 1960's.

During the last two decades, we have seen increasing use of advanced logging systems such as skyline, balloon, and helicopter yarding. These systems require less road construction and generally are less disruptive to soils because they minimize ground surface disturbance from skidding.

Scientists at the Intermountain Forest and Range Experiment Station's research laboratory in Boise began several watershed level studies in the mid-1960's to evaluate the impacts of various logging systems, with emphasis on comparative erosion and sediment production rates. These studies are located in the Silver Creek Study Area, about 75 mi (120 km) north of Boise. This paper reports results of studies of soil disturbance associated with the first logging in the area, clearcutting, and helicopter yarding. Future studies will include group selection and single tree selection harvests, and tractor-jammer skidding and skyline yarding systems.

STUDY DESIGN AND FIELD METHODS

Treatment

The logging treatment evaluated in this study was a 10-inch (25-cm) diameter limit cut, which essentially resulted in a clearcut because the stand was composed primarily of overmature ponderosa pine and Douglas-fir. Three small pockets of young ponderosa pine remained after logging. Total area of the cutting unit was 45 acres (18 hectares) and the volume removed was 12.3 M bd.ft./acre. All logs were yarded by helicopter. Slash was lopped and scattered, and then broadcast burned. Although conditions were fairly dry during the burn, discontinuities in slash cover over the unit resulted in a somewhat incomplete burn. Slash cover following this treatment will be discussed below.

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Slope steepness ranged from 30 to 50 percent on the cutting unit. Soils on the cutting unit are coarse textured and weakly developed. Two families of soils make up most of the unit: Sandy-Skeletal, Mixed Typic Cryorthents and Sandy-Skeletal, Mixed Typic Xerorthents. The soils are very similar; however, the Xerorthents are drier and warmer than the Cryorthents. These soils have one or more A horizons, typically with a total thickness ranging from 4 to 10 inches (10 to 25 cm), overlying C horizons. Bedrock contacts are generally shallower than 40 inches (10 cm). The texture of both A and C horizons is commonly gravelly loamy coarse sand or gravelly coarse sandy loam. Small inclusions of shallower soils are also found on the unit.

Two habitat types are found on the unit, both in the Douglas-fir series. Most of the unit is in the Douglas-fir/ninebark habitat type, but Douglas-fir/white spirea is also present. Douglas-fir and ponderosa pine were the major trees harvested.

Evaluation

I evaluated soil disturbance on 200 permanent 10.8 ft^2 (1 m^2) plots located at 32.8-ft (10-m) intervals along 10 transects. The transects ran in an east-west direction along the south-facing slopes. Because of the highly dissected nature of the slopes, the transects were only roughly on contour. The transects were spaced evenly through the central portion of the cutting unit.

Soil and cover conditions were evaluated immediately prior to the treatment, and three times over a 2-year period following treatment. Treatment and evaluation dates are shown in the following tabulation:

Date	Event
9/15/76	Pretreatment survey of soil conditions
9/20/76	Logging commences
11/18/76	Logging completed
2/7/77	Slash burned
5/20/77	First posttreatment survey
6/8/77	High intensity rain storm hits area
10/4/77	Second posttreatment survey
8/2/78	Third posttreatment survey

At each permanent transect point the following data were collected:

1. Areal coverage of slash (posttreatment surveys only);
2. Areal coverage of litter (01 and 02 horizons), litter depth;
3. Live ground cover percent, canopy coverage within 1 foot of soil surface;
4. Soil horizon mixing (0 and A, and/or A and subsoil horizons), areal coverage and depth;
5. Erosion, areal coverage and depth;
6. Type and cause of erosion, if ascertainable.

From these data we were able to evaluate slash added to the site after logging, loss of litter protection after logging and burning, live ground cover changes, and soil disturbance (either erosion or mixing) by cause.

Areal coverage was estimated by using a 10.8 ft^2 (1 m^2) frame that was subdivided into 25 equal sized squares, each 0.43 ft^2 (0.04 m^2). The frame was placed over corner stakes marking each permanent plot. Coverage, such as slash, litter, and erosion scars, was visually estimated by direct viewing from above. Each of the 25 smaller squares was viewed individually, and coverage summed to provide a final coverage figure for the plot. I tested the ability of different individuals to replicate litter coverage estimates using this technique. Maximum variance was 2 percent for coverage estimates ranging from 38 to 99 percent on 10 individual plots. Estimates of soil disturbance, live vegetation cover, or slash were not similarly tested. Replication might be expected to be poorer for live vegetation and slash because of the greater vertical zonation.

RESULTS AND DISCUSSION

Ground Cover

The protection afforded soil by ground cover and its influence on erosion have been conclusively demonstrated. Packer (1963) pointed out that surface erosion on elk winter range in Wyoming increased markedly when ground cover density dropped below 70 percent. Meeuwig (1970a,b) also emphasized the importance of ground cover in reducing erosion on Intermountain rangeland sites. He stated that the magnitude of erosion from raindrop impact depended primarily upon surface protection imparted by plants, litter, and surface stone. In the Idaho batholith, Megahan and Kidd (1972) studied surface erosion on disturbed areas and again emphasized that treatments to restore disturbed areas should ensure protection of the soil surface until vegetation is reestablished. Mersereau and Dyrness (1972) showed that surface erosion by dry ravel increases on slopes unprotected by organic debris, and that plant cover is essential to restore stability. The Mersereau and Dyrness (1972) study in western Oregon was made on a conventional clearcut with burned slash, a treatment similar to that used on the study area in this report.

Ground cover protects the soil in a combination of ways, including energy dissipation of rainfall, wind, and, in some cases, overland flow of water. Surface litter also promotes infiltration by detaining large volumes of water that would otherwise result in overland flow.

We measured changes in ground cover protection from slash, litter, and live vegetation before and after logging.

LASH

The prescription for slash disposal was lop and scat-
er followed by broadcast burning. The burn was somehat incomplete and resulted in a fair cover over the soil urface of unburned slash and partially burned logs and mbs. Prior to logging, any limbs or logs lying on the round were considered part of the litter layer; so the relogging survey recorded no slash cover.

At the time of the first postlogging survey, areal overage of slash was 22 percent, and depths ranged om 0.25 inch to 40 inches (0.6 to 100 cm); average epth was 4 inches (10 cm) over the area with slash resent. Fourteen percent of the total slash measured real coverage) was in needles fastened to branches.

Slash cover decreased to 15 percent when the secnd postlogging survey was made in October 1977, a ear after logging. Four percent of the total slash overage was needles connected to branches. The ecrease in total slash cover was in part attributable to eedlefall, but much of the loss may have been due to nall twigs and branches breaking off of limbs and no nger recognized as slash. This, however, was not cked up as an increase in the percent litter coverage n the plots.

A high intensity summer rainstorm hit the area beveen the first and second postlogging surveys. A cording raingage located approximately 1,000 feet 00 m) from the nearest plots indicated a rainfall tensity of 3 inches/h (76 mm/h) with a duration of 2 inutes followed immediately by 0.3 inch/h (8 mm/h) orm lasting 9 minutes. Much of the smaller slash ay have been carried by surface wash and concenated in pockets accounting for part of the decrease in ash coverage.

The third postlogging survey, 23 months after treatent, indicated slash coverage had decreased to 12 ercent, with needles still fastened to branches making only 2 percent of this figure. Over the 2-year period, ash coverage decreased from 22 percent to 12 perent. Although we do not have data on size of slash xcept for needles), there was an obvious and logical end toward larger pieces of slash remaining on the site ith time. Percent coverage by needles decreased om 3 percent (14 percent of 22 percent) to 0.2 perent (2 percent of 12 percent) over 2 years. The average epth of slash remained essentially constant, being ainly a function of depth of mutually supporting piles branches

ITTER

Prior to logging, litter covered 83 percent of the soil urface to an average depth of 0.9 inches (2.3 cm). Most (96 percent) litter was in the form of needles and mall twigs; the remainder was in larger branches, logs, nd deciduous leaves.

After logging and broadcast burning, litter coverage decreased to 75 percent at the time of the first posttreatment survey. More than 90 percent of this 8 percent decrease was directly attributable to the fire. In other words, the litter decrease from 83 percent to about 82 percent was attributable to mechanical disturbance associated with felling, setting choker cables, and removing logs from the site. The reduction from 82 percent to 75 percent was due to the combustion of dry litter. Average litter depth in this survey was again 0.9 inches (2.3 cm).

Areal coverage of litter decreased to 68 percent by the time of the second postlogging survey. This decrease was similar in magnitude to the slash decrease during this period, and again may be due to the high intensity rainstorm on the area. Of the 200 plots evaluated, 16 were considered totally unchanged between the prelogging and first postlogging surveys. These plots apparently were not disturbed by logging because no merchantable trees were in the immediate vicinity; so there were no slash additions and the fire did not burn these plots. Litter cover on these undisturbed plots averaged 72 percent prior to the rainstorm and 67 percent after the storm. These percentages tend to corroborate the suggestion that the litter decrease from 75 percent to 68 percent on all plots was indeed due to the storm, rather than to some logging-related disturbance.

Litter cover after 2 years was estimated at 69 percent and considered to be unchanged from the second posttreatment survey. Average litter depth was 0.8 inches (2 cm) on this survey, indicating that litter depth apparently was not affected by treatment over the duration of the study.

LIVE GROUND COVER

Canopy coverage of live plants to a height of 1 ft (0.3 m) above the soil surface was recorded prior to logging and during the second and third posttreatment surveys, 1 and 2 years following harvest. Canopy coverage above 1 ft (0.3 m) does intercept rainfall, but its direct effect on soil protection is difficult to evaluate. Canopy coverage for this study was primarily restricted to graminoids (elk sedge and pinegrass), forbs (arrowleaf balsamroot, dogbane, heartleaf arnica, and several others), and small shrubs (ninebark, Scouler willow, spirea, and many others).

Prior to logging, live plant canopy cover averaged 29 percent, but had decreased to 8 percent when measured 1 year after the logging and fire. From visual observation, I attribute essentially all of this decrease to the fire. Conditions for plant regrowth during the first year were poor, as this was the driest winter on record in the Northwest. Most of the live vegetation remaining was elk sedge that had not burned.

The second year, live vegetation increased to cover 15 percent of the ground surface. Many forb seedlings and small shrubs, notably snowbrush ceanothus, that were not present the previous year sprouted during the spring and summer of 1978.

Soil Disturbance

Soil disturbance below the litter layer was evaluated by measuring areal coverage and depth of soil horizon mixing and erosion within the 1 m^2 plots.

SOIL MIXING

The mixing of soil horizons is relatively easy to determine in the field. When 0 horizons are incorporated with underlying A horizon material there is obvious disruption of A horizon structure, disaggregation, and a general sense of mechanical disturbance to the soil. A mixing of the A and subsoil horizons is less common, requiring deep churning of the soil, but the mixing is also readily recognizable. Soil mixing loosens soil particles and makes a soil more susceptible to erosion. Mixing also interferes with the normal vertical gradients of nutrient distribution in a soil and disrupts nutrient cycling processes.

Prior to logging 1 percent of the area evaluated was considered to exhibit some degree of soil mixing. This percentage included a total of 20 observations of mixing, eight of which were attributable to animal activity, such as game trails or pocket gopher casts. The other 12 cases of soil mixing were difficult to categorize as to cause. Most appeared to be related to a common ongoing erosion/deposition process on the slope, such as dry creep or sheet erosion, which resulted in mixing of litter with lithic soil grains. All soil mixing recorded in the pretreatment survey was shallow, less than 1 inch (2.5 cm) deep.

I recorded 62 separate soil mixing events during the first posttreatment survey. Total area disturbed by soil mixing was nearly 5 percent. Many soil mixing events recorded during the pretreatment survey were not observed after the treatment, presumably because fire destroyed the evidence. Twelve (19 percent) of the mixing occurrences were attributable to animals (pocket gophers and two game trails); 26 (42 percent) to direct mechanical disturbance caused by logging; and 24 events (39 percent) that I could not categorize. Most of these events again appeared to be related to shallow slope erosion/deposition processes. Average depth of soil mixing surveyed was 1½ inches (4 cm); deepest mixing was 4 inches (10 cm).

On the second postlogging survey, 61 soil mixing events were tallied. Several of the previously recorded mixing events became erosional events following the storm; however, there was considerable new mixing due to gophers. Nearly 5 percent of the total area remained in the soil mixing category. Seventeen events (33 percent) were caused by animals. Fifteen of these events were pocket gopher casts. Mechanical disturbance due to logging accounted for 24 events (47 percent), and the other 10 events (20 percent) were due to unknown causes.

On the final survey, there were 50 soil mixing events recorded, with 3 percent of the soil area disturbed. Animal activity accounted for 20 events (40 percent) of the disturbance, 19 events (38 percent) were attributed to mechanical effects of logging, and 11 events (22 percent) were of unknown origin. The following tabulation summarizes the data on soil disturbance by mixing caused by various agents:

Survey	Animals	Logging	Other	Percent area disturbed
	No. %	No. %	No. %	
Prelogging	8 (40)	— —	12 (60)	1
First postlogging	12 (19)	26 (42)	24 (39)	5
Second postlogging	17 (33)	24 (47)	10 (20)	5
Third postlogging	20 (40)	19 (38)	11 (22)	3

An increase in soil mixing caused by pocket gopher ıctivity was one very notable trend after logging. Other esearchers studying response of small mammals to ɔgging in the same cutting unit found similar increases ı pocket gopher casts, particularly in large openings reated by the logging and the fire (personal com- ıunication, Dean E. Medin).

;OIL EROSION

Estimates of erosion were made within the bound- ries of the 10.8 ft^2 (1 m^2) plots by measuring areal overage and mean depth of depressions presumably esulting from rilling, deflation, or mechanical removal of oil during logging activities. Erosion volume was onverted to a weight basis assuming a soil bulk density f 1.3 g/cm^3. Depressions resulting from stump and oot burnout following the fire were not considered rosion. Deposition of soil from upslope erosion was nly recognized on one plot and was not considered to e a gain. Permanent vertical reference points, such as rosion pins, would have been helpful in determining oil deposition and erosion from processes such as dry reep, that do not leave recognizable depressions; this versight was not realized, however, until most erosion ad taken place.

Natural erosion volumes were estimated on the basis f two different surveys: total erosion was measured uring the prelogging survey and erosion volumes were ıeasured on the 16 plots that were known to be ndisturbed by logging and burning. The total erosion gure was not truly a rate since the timespan over which ecognizable erosion took place is unknown. Rodent ctivity, known to have increased following logging, robably affected postlogging erosion rates on these lots, but can be roughly accounted for.

Based on the prelogging survey, natural erosion was 04 ton/acre (0.09 t/ha). Forty percent of this was tributable to two game trails running through the ots. The remaining 60 percent was attributed to ırface erosion of hydrologic origin (small rills). Erosion vents were recognized on five of 200 plots during this ırvey.

Erosion volume on the 16 undisturbed plots equalled 6 ton/acre (1.3 t/ha) during the second posttreat- ent survey following the rainstorm. No previous osion was measured on these plots. I determined that 3 ton/acre (0.7 t/ha) could be attributed to sheet osion from the storm and that 0.3 ton/acre (0.6 t/ha) as primarily caused by gopher damage. Based upon is small sample, there is an approximate order of agnitude difference in the natural erosion rate due to e influence of a single high intensity rainstorm.

The erosion measured during the first posttreatment survey conducted in May 1977, all plots included, was 0.85 ton/acre (1.9 t/ha). Essentially all of this erosion was caused by mechanical disturbance associated with the logging and occurred on 11 of the 200 plots surveyed. Erosion was due to gouging and scraping during felling and yarding operations. During this first posttreatment survey, no accelerated erosion was attributed to the fire.

Evidence of erosion increased dramatically during the second posttreatment survey in October 1977. Erosion was observed on 34 plots. The estimated weight of eroded materials was in excess of 6 tons/acre (14 t/ha). Of this 6 tons/acre, as mentioned above, 10 percent or 0.6 ton/acre was considered to be natural erosion occurring on undisturbed plots. The remaining erosion was partitioned by cause as follows: 2.5 tons/acre (5.6 t/ha) were attributed to mechanical disturbance accelerated by the storm; 2 tons/acre (4.5 t/ha) were attributed to sheet erosion on plots that were previously denuded by the fire; and the remaining 1.2 tons/acre (2.6 t/ha) were not attributed to any single cause. All of the erosion not attributed to a single cause (1.2 tons/acre) occurred on plots previously disturbed by fire or logging. Gopher damage on bare soil disturbed by the fire had occurred on many of the plots included in this final group. Figure 1 graphically presents the erosion-by-cause data 1 year after logging.

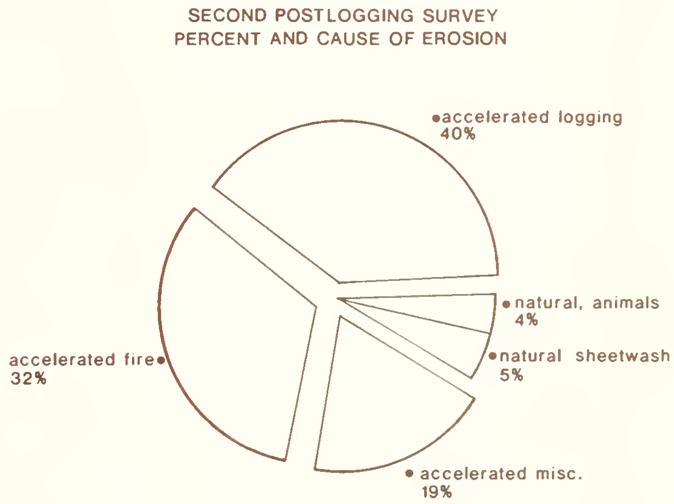

Figure 1.—Data on percentage of erosion by cause are presented in this figure. These data were gathered in October 1977, 1 year following logging and broadcast burning. Accelerated erosion is shown by the expanded sections of this pie diagram.

The percentage erosion attributed to various causes, such as logging, fire, and natural causes, remained essentially unchanged between the second and third posttreatment surveys (October 1977 to August 1978). The amount of erosion decreased from 6 tons/acre (14 t/ha) to 4 tons/acre (9 t/ha). This decrease was the result of 12 slightly eroded plots that stabilized during the third posttreatment survey. Two of the more severely eroded plots continued to lose soil material, and erosion estimates on these plots increased.

TOTAL AREA OF SOIL DISTURBED

The total area of soil disturbance attributable to the logging and slash disposal was 19 percent. Seventy-four percent of this disturbed area (14 percent of the total area) was caused by loss of litter, mainly due to the fire. Sixteen percent (3 percent of the total area) was due to soil mixing, generally resulting from mechanical disturbance during logging and to rodent activity. The remaining 10 percent (2 percent of the total area) was considered to be actively eroding due to the combined effects of logging and burning.

Dyrness (1967, 1972) published results of soil disturbance associated with skyline and balloon logging, two other yarding systems considered to cause relatively minor soil disturbance. Although our techniques of evaluation differ somewhat, our data can be compared and the results are similar. Dyrness (1967, 1972) described area of disturbance by classes as follows:

Undisturbed.—Litter still in place and no evidence of compaction.

Slightly disturbed.—Three conditions fit this class:

1. Litter removed and mineral soil exposed;
2. Mineral soil and litter intimately mixed;
3. Mineral soil deposited on top of litter.

Deeply disturbed.—Soil surface removed and subsoil exposed.

Compacted.

The following tabulation compares results of soil disturbance by helicopter logging shown in this study with results of soil disturbance by skyline and balloon logging (Dyrness 1967, 1972):

Classes	Skyline	Balloon	Helicopter
Undisturbed	63.6	78.1	81
Slightly disturbed	24.4	15.8	17
Deeply disturbed	4.7	2.6	2
Compacted	3.4	1.7	not evaluated

CONCLUSIONS

Clearcut logging with helicopter yarding appears to cause minimal onsite soils disturbance when compared with other, more conventional logging systems (Dyrness 1965, 1967). Accelerated erosion was found on 2 percent of the area, and volume estimates indicate a short-term increase of approximately one order of magnitude. Eroded areas appear to be healing 2 years after the treatment.

Broadcast burning of slash resulted in litter losses on approximately 14 percent of the total area. This contributed to the acceleration of erosion and also resulted in a loss of a valuable nutrient sink. Although many nutrients contained in litter may have remained on the site in ash, some nitrogen and sulfur have been lost through volatilization. Cations in the ash are quite mobile and leaching loss is likely. Other methods of slash disposal including jackpot burning will be evaluated in future studies at Silver Creek.

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Research Note
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Differential Defoliation of Neighboring Douglas-fir Trees by Western Spruce Budworm

G. I. McDonald[1]

ABSTRACT

Color photographs document phenotypic variation of inland Douglas-fir populations in response to attack by western spruce budworm. Host-insect literature was reviewed and tentative hypotheses to explain the nondefoliated trees are suggested. The implications these various possible explanations have on future breeding programs are discussed.

KEYWORDS: budworm resistance, *Pseudotsuga menziesii, Choristoneura occidentalis,* insect resistance progeny tests

Little is known of the host-pest genetic interactions in an ecosystem sense, but some sort of resistance-susceptibility, virulence-avirulence (or preference-nonpreference) polymorphology is known for every system that has been studied, such as chestnut blight caused by *Endothia parasitica* (Van Alfen and others 1975), stem rust of wheat caused by *Puccinia graminis* (Browning 1975), codling moth (*Laspeynesia pomonella*) on pears and apples (Westgard and others 1976), nymphaline butterfly (*Euphydryas editha*) on various host plants (Singer 1971), bluegrass billbug (*Sphenophorus paroulus*) on bluegrass (*Poa pratensis*) (Kindler and Kinbacher 1975), and fusiform rust (*Cronartium fusiforme*) on southern pine (Snow and others 1976). Many more systems exhibit the more easily discerned polymorphology of variation in the host; for example, white pine blister rust caused by *Cornartium ribicola* (Bingham and others 1971); Douglas-fir needle cast caused by *Rhabdocline pseudotsugae* (Brandt 1960); *Lecanastecta* spp. causing needle cast on western white pine (Hoff and McDonald 1978). Also, Douglas-fir (*Pseudotsuga menziesii*) shows a polymorphic population in response to feeding damage by hare and deer (Dimock and other 1976).

Long-term host:pest interaction leads to a coevolved genetically interdependent system (Anikster and Wahl 1979; Harlan 1976; Price 1977). The degree of interdependence depends on time, environment through which time operated, current environment, and the genetic configurations of both host and pest at the beginning. Current theory indicates that the interdependent host-pest systems should be maintained because of the likelihood of drastic reduction of the host if only the host side is tampered with (Price 1977).

Consequently, the first step in any pest control effort should be to determine how much input natural forces, including genetic variation of host and pest, can make to the overall pest management effort (Kogan 1975). Costs skyrocket when control strategies ignore or defy these forces. The white pine blister-rust antibiotic

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spray program and *Ribes* eradication in the West are examples (Ketcham and others 1968). Much evidence generated in the development of control strategies for pests (including insects) of agricultural crops shows that a factor of prime importance to integrated control programs is the genetic interaction between the host population and the pest population (Tummala and Haynes 1977). Thus, regardless of the control strategy ultimately selected to deal with the western spruce budworm (*Choristoneura occidentalis*), a basic piece of information is the role host resistance plays in the interaction between budworm and its hosts.

The initial genetic question is: Does phenotypic variation of the desired trait exist? Because genetic theory holds that phenotypic variation is composed of two parts—variation due to environment and variation due to genes—the following implication can be formulated: If Douglas-fir populations possess inherited resistance to western spruce budworm, then phenotypic variation in amount of damage after similar exposures to western spruce budworm should be observable in trees growing in the same environment. If no phenotypic variation is readily observed, then inherited traits will be difficult to detect. So, existence of phenotypic variation would signify the possible existence of a genetic component in the Douglas-fir, western spruce budworm interaction.

Phenotypic Variation of Spruce and Balsam Fir

Most information available deals with white spruce (*Picea glauca*) and balsam fir (*Abies balsamea*) damaged by the eastern spruce budworm (*Choristoneura fumiferana*), in eastern Canada. Typically, 90 to 97 percent of the merchantable balsam fir is destroyed during an outbreak that runs its full course (Blais 1954; Ghent 1958). On the other hand, few understory seedlings of balsam fir are killed (Ghent 1958).

During an outbreak, white spruce intermingled with balsam fir is much less subject to mortality (Ghent and others 1957) than the balsam fir. Specific estimates of white spruce mortality were not found, but there is a striking difference in mortality levels between white spruce and balsam fir. More information is needed in order to determine why white spruce is more resistant than balsam fir.

Comparison of radial growth patterns between host and nonhost trees growing in eastern Canada (Blais 1954, 1965, 1968) demonstrates that many white spruce and an occasional balsam fir can survive repeated budworm outbreaks. At one location in Quebec, six white spruce were found that had each survived six outbreaks over the last 300 years. Blais does not state how many balsam fir were included, but apparently several around 125 years of age were found. These balsam fir trees survived two outbreaks between 1835 and 1960. Specific references to resistance in these species to eastern spruce budworm have not been found, but survival of individuals through repeated outbreaks argues for their possession of phenotypic resistance.

Phenotypic Variation of Douglas-fir

Many Douglas-fir growing in the Montana Rocky Mountains survive severe budworm outbreaks (Johnson and Denton 1975). Also, 1-year-old Douglas-fir seedlings showed a significant amount of stand related variation in degree of defoliation after exposure to field-collected third and fourth instar *C. occidentalis* larvae (McDonald 1979). Because references are not available, we conducted a search for cases of differential defoliation and survivorship in outbreaks of western spruce budworm in Douglas-fir stands of Montana and Idaho.

The purpose of this paper is to document the results of this search and interpret the findings in preparation for future progeny tests and breeding programs.

METHODS

We searched for stands of Douglas-fir that have withstood budworm outbreaks or are currently being severely defoliated. Side-by-side cases of dead-living and defoliated-undefoliated trees were photographed. Each member of a photographed pair was required to be about the same size, have their branches intertwined, and their roots growing in similar soil. We attempted to obtain pairs located at several different locations to survey a variety of outbreak conditions and stand ages. For this initial survey, data consisted of photographs of pairs and some closeup comparisons of branches. An analysis of radial growth data will be the subject of another report. Phenotypic variation was documented in the following stands:

Lolo National Forest:
- Cedar Creek—lower R. 26 W., T. 16 N., S. 22; upper R. 27 W., T. 15 N., S. 8 and 9; middle R. 27 W., T. 16 N., S. 33.
- Camel's Hump—R. 28 W., T. 19 N., S. 32.
- South Fork, Little Joe Creek—R. 30 W., T. 17 N., S. 5

Helena National Forest:
- Sheriff Gulch—R. 1 E., T. 11 N., S. 3.

Lewis and Clark National Forest:
- Spring Creek—R. 10 E., T. 10 N., S. 11.
- Green Mountain—R. 7 E., T. 11 N., S. 3.

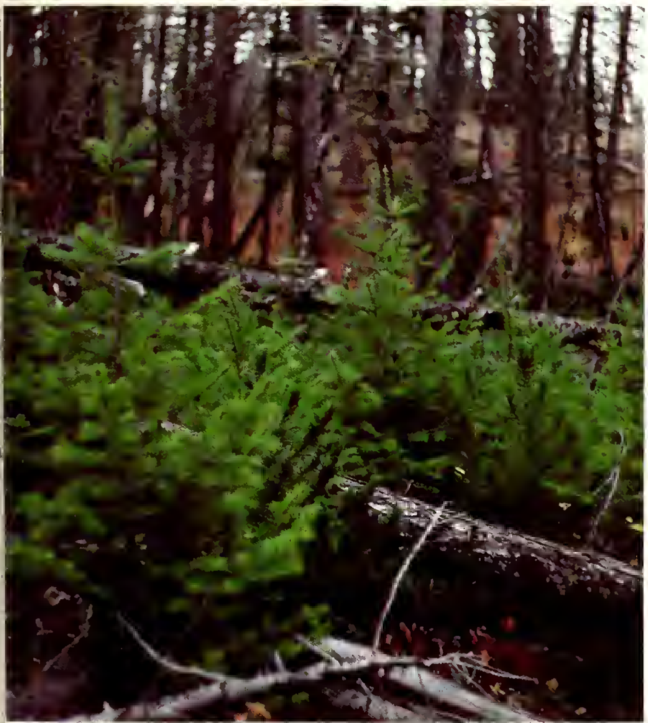
Payette National Forest:
- Goose Creek—R. 2 E., T. 19 N., S. 15.

Salmon National Forest:
- Hull Creek—R. 20 W., T. 25 N., S. 24.
- Panther Creek—R. 21 W., T. 21 N., S. 33.

RESULTS

At Spring Creek on the Lewis and Clark National Forest near White Sulfur Springs, Mont., there are clearly several survivors of an intense epidemic (fig. 1, photographed in July 1975 about 10 years after the outbreak collapsed). In 1978 these survivors were still under attack but they were growing well. Much regeneration about 10 years old was also evident under the survivors (fig. 2).

Figure 1.—Douglas-fir trees 150 to 200 years old that survived intense epidemic of mid-1960's. Spring Creek drainage on the Lewis and Clark National Forest. Photo taken July 1975.



-igure 2.—Douglas-fir reproduction in the Spring Creek stand. Photo taken in October 1977.

On the South Fork of Little Joe Creek on the Lolo ıational Forest near St. Regis, Mont., in early October 977, we observed striking differential defoliation of)ouglas-fir reproduction about 8 to 10 ft (2.4 to 3 m) in ıeight. As seen in figure 3, the tree on the right edge of ıe photo was evidently much less severely defoliated ıan the trees on the left and in the middle.

In early September 1978, we observed a stand ɔcated in the Cedar Creek drainage on the Lolo Na-onal Forest near Superior, Mont. In figure 4, four levels f defoliation that vary from nearly complete (tree to the nmediate left of the full-crown tree) to almost no efoliation are evident. In figure 5, four defoliated and

Figure 3.—Differential defoliation of Douglas-fir reproduction in the South Fork of Little Joe Creek drainage on the Lolo National Forest during a budworm outbreak. Photo taken in early October 1977.

Figure 4.—Differential defoliation of Douglas-fir stems during an outbreak in the Cedar Creek drainage on the Lolo National Forest. Notice undefoliated crown at photo center entwined with defoliated corwn. Photo taken in early September 1978.

two nondefoliated crowns are clearly visible. Many of the nondefoliated crowns were producing cones in 1978 even though the epidemic did not collapse until the summer of 1978.

Another differential reaction was recorded from the Camel's Hump area near St. Regis in late June 1978. Field observations of several pairs of heavily defoliated and lightly defoliated Douglas-fir showed in each case very striking differences. The heavily defoliated trees all exhibited severe top kill, much bud kill, and foliage was

Figure 5.—Differential defoliation of 75-100 year old seed-bearing Douglas-fir in the Cedar Creek drainage on the Lolo National Forest. Photo taken in early September 1978.

Figure 6.—Close-up of defoliated branches from mid-crown of 75 to 100 ft tall Douglas-fir growing on Camel's Hump near St. Regis, Mont. Two branches on left from "green crown" and three branches on right from "gray crown." Photo taken in late June 1978.

largely limited to the current year's needles. Many budworms were evident on both nondefoliated and defoliated trees. Defoliation and budworm population estimates were made on sample branches taken from midcrown of trees 40 to 75 ft (12 to 22 m) tall. One comparison of defoliation on trees about 60 ft (18 m) tall is shown in figure 6. The green member of the pair (branches on the left) exhibited no evidence of top kill and few dead buds, 50 to 95 percent of the foliage remained on the last 6 years of branch wood, and even though this tree contained a much larger number of

Figure 7.—Dead and "full crown" old growth Douglas-fir a Green Mountain, Lewis and Clark National Forest, about 10 years after collapse of outbreak. Photo taken July 1975.

Figure 8.—Comparison of grand fir (tree on left) and Douglas fir (tree on right) defoliation. Goose Creek, Payette Nationa Forest. Photo taken September 1978.

feeding sites (branch tips) it supported an estimated 6 to 90 percent fewer larvae than the crowns represente by the branch on the right.

In mid-july 1975, we visited a stand located on Gree Mountain near White Sulfur Springs, Mont. Figure 7 shows a typical "full-crown" survivor of a severe out break that had collapsed about 10 years before. I early October 1977, we took branches from suc crowns at Green Mountain for rooting studies and note some current defoliation.

A stand of mixed grand fir (*Abies grandis*) an Douglas-fir growing on Goose Creek of the Payett National Forest was visited in early September 1978 This stand contained a young Douglas-fir (small tree o the right, fig. 8) with a complete crown and a youn grand fir (small tree on the left, fig. 8) with sever defoliation. But directly across a dirt road about 50 (15 m) from the nondefoliated Douglas-fir was the crow shown in figure 9, a Douglas-fir that was almost com pletely defoliated.

Figure 9.—Heavy defoliation of a small Douglas-fir tree about 50 ft from the nondefoliated Douglas-fir shown in figure 8.

Figure 11.—Intertwined crowns of defoliated and nondefoliated Douglas-fir (close-up in fig. 10) in the first year of an outbreak. Hull Creek, Salmon National Forest. Photo taken September 1978.

Figure 10.—Close-up of mid-crown samples from adjacent Douglas-fir shown in figure 11 at end of first season's defoliation by western spruce budworm. Hull Creek, Salmon National Forest. Photo taken September 1978.

Figure 12.—Nondefoliated and defoliated Douglas-fir in a chornic outbreak. Panther Creek, Salmon National Forest. Photo taken September 1978.

A new outbreak of western spruce budworm was under way on the Salmon National Forest in 1978. We visited some of these stands in early September 1978. One case at Hull Creek shows very clear differential defoliation. The branches shown in figure 10 came from the same level in the crowns of the two forward trees in figure 11. The current foliage of the tree directly to the left of the arrow (fig. 11) was almost completely gone (branch on left of fig. 10) while the tree on the right shows almost no defoliation (branch on right of fig. 10). A comparison found at Panther Creek on the Salmon National Forest shows much the same thing

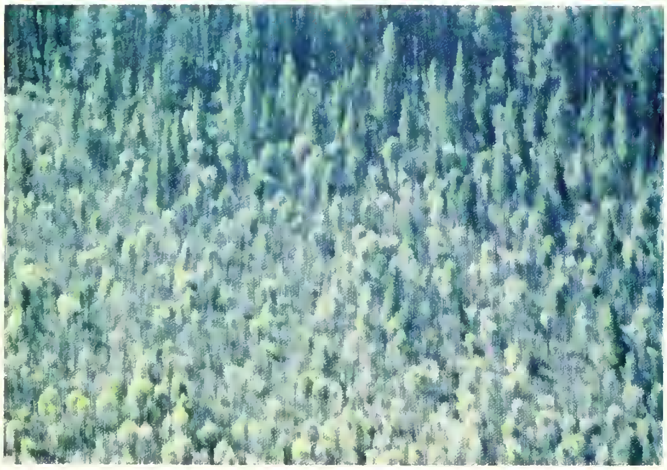


Figure 13.—Green crowns after an intense outbreak in a densely stocked pure Douglas-fir stand. Sheriff Gulch, Helena National Forest. Photo taken July 1975.

Figure 14.—Close-up of the green crowns in figure 13. Notice the number of dead stems. Sheriff Gulch, Helena National Forest. Photo taken July 1975.

except that this area apparently had a chronic infestation. The tree on the right in figure 12 has apparently been subjected to many years of repeated defoliation.

The last area to be discussed is Sheriff Gulch on the Helena National Forest. A telephoto photograph (fig. 13) shows the distribution of surviving crowns in a severe outbreak in relatively young Douglas-fir. The relatively high level of mortality in this stand is shown in figure 14. Rooting material was collected from this stand in early October 1977, and evidence of light to medium defoliation was observed in the surviving crowns.

DISCUSSION

The defoliation polymorphism reported by Johnson and Denton (1975) seems to be widespread in Douglas-fir populations subjected to western spruce budworm defoliation. Does polymorphism indicate the existence of a potential budworm management option? The answer depends on the factors causing the condition and their amenability to management. The objective of this discussion is to examine possibilities and develop testable hypotheses that will explain the existence of "green" Douglas-fir. Propositions to be examined include moth escape; physiographic location; moth oviposition preference; hibernacular site selection of first instar larvae; larval feeding preference, including foliage toxicity; pheromone chemistry; parasite and predator effectivenes; and host-insect phenologic asynchrony. In the conclusion, we will discuss the impacts of the hypothesized relationships on a possible breeding program.

Escape

The green trees could be the result of escape. I find it difficult to accept this explanation given time available and budworm numbers and behavior patterns during outbreaks. The most powerful argument against escape is that as the outbreak builds, the foliage of most trees is almost entirely consumed. Thus the green trees become a resource in ever increasing demand by a much increased population. Yet, they remain green.

Physiographic Location

The undefoliated trees could be growing on a microsite that renders them less desirable to the budworm or more desirable to some budworm predators or parasites. We could not find any literature pertaining specifically to this proposition. Also, the current study was designed to minimize this possibility. The comparisons were made from the viewpoint of eliminating microsite variation. If the polymorphism cannot be explained satisfactorily by the other propositions, we would give this one more weight and accept the possibility that host-insect genetic interaction is not playing a role.

Moth Oviposition Preference

The green trees may have resulted from receiving fewer eggs than their neighbors during an outbreak. Does *Choristoneura* exhibit oviposition preference? There are at least two mechanisms leading to oviposition preference. The first deals with directed host selection through use of the senses of sight and of smell. Female *Heliconius* butterflies are known to possess a complex system that utilizes both senses fo oviposition-host selection from members of the famil *Passifloraceae* (Benson and others 1974). A large liter ature has developed over the last few years that detail many of the specific host-oviposition interactions a well as other plant-insect communications. Much c this knowledge was summarized by Kogan (1977) i his development of six classes of host-selection stra tegies. Since the budworms most likely fall into Kogan' class V where oviposition is selective, we can assum that a *Choristoneura* female actively selects hosts.

The second mechanism of host selection for ov position is the passive process exemplified by oa winter moth (*Operopthera brumata*) (Feeny 1976) an other moths characterized by flightless females. In these situations, because of lack of mobility, the females are obliged to oviposite on their food genotype. *Choristoneura* seems to exhibit an intermediate response. Well-fed females probably lay most of their eggs on their food genotype, judging from the Sander and Lucuik (1975) findings about the effects of photoperiod and moth size on flight and oviposition behavior. More well-fed females laid eggs before they tried to fly than the starved insects. In fact, most starved insects flew before they oviposited. Thus, under conditions of low defoliation most eggs are probably laid on the female's food genotype, and under high defoliation most eggs would be laid after dispersion.

Hibernacular Site Selection

Choristoneura spends the first 1 to 5 days after hatching searching for a suitable hibernation site (Harvey 1957). Wellington and Henson (1947) reported that *C. fumiferana* larvae crawled from the egg onto the needle and then moved toward the needle tip. If overcrowding occurred, many of the larvae would "drop" from the crowded needles. The question is whether or not the larvae "drop" directly from the egg. Do first instar larvae communicate with the tree on which they hatch? There is some evidence that oak leaf roller females can "imprint" their eggs with a chemical message to their larvae to exhibit a feeding preference for the female's food genotype (Hendry and others 1976). Such an imprint could be passed to first instar larvae so that the larvae could decide whether to drop directly from an egg or to crawl onto the surface of the needle depending on whether or not the egg was located on the female's food genotype. Budworm larvae spin a thread at all times (Harvey 1957). Thus, some of their actions can be inferred from their "tracks." We observed threads hanging directly from hatched eggs of all three clusters on one 6-year-old Doulgas-fir (author's unpublished data). Does this mean that these larvae dropped without crawling? Conversly, we have observed newly hatched larvae crawling from eggs to needle surfaces when eggs were depositied on needle population composed of the female's food genotypes.

Larval Feeding Preference

Upon completion of diapause requirements and onset of warmer spring weather, the hibernating larvae become active and start searching for feeding sites. They generally mine the previous year's needles, new vegetative buds, or developing floral parts. Much literature indicates various kinds of chemical messages may be involved in determination of insect feeding sites. Some of the possibilities are specific or general excitants and restricted or general deterrents (Kogan 1977). There is considerable current interest in the general and specific feeding deterrents (Rhoades and Cates 1976).

A different mechanism of specificity determination (Hendry and others 1976; Rodriguez and Levin 1976) involves the "imprinting" of eggs with a substance obtained by the female from the plant she fed on. Hendry and others (1976) reported that such a system may be operating in oak leaf roller populations. They show that larvae of oak leaf roller hatching from eggs laid on scarlet oak prefer to feed on scarlet oak. But in the early instars, they will feed on other species of oak. Last instar larvae reared on scarlet oak will not feed on other oak species. The larvae die rather than feed. When oak leaf roller larvae are forced to feed on black oak during early instars they will not change back to scarlet oak in the last instar.

In light of recent findings, a contribution by the male to any imprint must be considered a possibility (Boggs and Gilbert 1979). Male Lepidoptera were shown to supply nutrients to the female through the sperm and spermatophore. These nutrients found their way into both the female and her eggs. Some plant products are presumably passed to budworm eggs from the female because *C. fumiferana* reared on artificial diet lay blue eggs as opposed to the normal green eggs (McMorran 1965).

Another example of food selection concerns two moths of the family Tortricidae. They are believed to be general angiosperm feeders that also occasionally feed on conifer seedlings (Martin 1958). Both *Tortrix alleniana* (*Aphelia alleniana* according to McKay 1962) and *Tortrix pallorana* (*I. clemensiana, Spraganothis sulfurerna, Amelia apllorama*, and *Aphelia pallorama* according to McKay 1962) were observed to behave as follows. Eggs were laid almost exclusively on white sweet clover (*Melilotus alba*) and alfalfa (*Medicago setiva*). Upon hatching larvae dispersed to find feeding sites. If they found a site on either white sweet clover or alfalfa they remained there to pupation. On the other hand, if they began feeding on other herbaceous plants, they frequently found their way to various conifer seedlings. Feeding times on these conifers varied from short to extended. These observations can be interpreted to agree with the oak leaf roller hypothesis. No evidence was given as to the oviposition preference of the moths raised on nonpreferred hosts or on the food preference of the resulting larvae.

Pheromone Chemistry

Before we discuss other possible explanations for the existence of green trees, we should look at the role of pheromones, since patterns of variations in pheromone chemistry coupled with differentiation of budworm populations on individual host plants could account for the observed defoliation patterns. Host plants apparently can play a significant role in the pheromone chemistry of some insects (Hendry and others 1976) and intraspecies host-mediated-differentiation of insect populations is a real possibility (Feeny 1976; Edmunds and Alstad 1978). European cornborer (*Ostninia nubilalis*) can produce at least three kinds of pheromone based on the proportion of Z and E isomers of 11-tetradecenyl acetate (Klun and Maini 1979). These pheromonal differences are expressed as genetically controlled traits that are characteristic of different populations of European cornborers. Corn varieties produce different ratios of tetrodecenyl acetate isomers, so corn chemistry might influence cornborer gene pools through its control of mating (Hendry and others 1976). Budworm-Douglas-fir could interact in a similar fashion.

Parasite and Predator Effectiveness

Reduced defoliation could result from a plant-produced or plant-influenced kairomone. For example, a wasp parasite, *Orgilus lipidus*, of the potato tuberworm moth (*Phthorimaea opercullella*) responds to heptanoic acid with typical host searching behavior (Hendry and others 1976) and the heptanoic acid is produced by the potato plant. Thus, the possibility that certain Douglas-fir genotypes can produce more effective kairomones than their neighbors must be examined. The attack rate of *Glypto fumiferanae*, a specific Ichneumoid parasite of first and second instar larvae of *C. fumiferanea*, was reduced two to four times on heavily defoliated *Avies balsame* as compared to lightly defoliated *A. balsame* (Miller 1960). These results could be explained on the basis of kairomone production as well as on other bases. There are at least 39 different parasitic species (Miller and Renault 1976) that could function in all manner of different combinations.

Host-Insect Phenologic Asynchrony

The last hypothesis to come to mind is phenologic asynchrony. Since budworm and related moths apparently require a specific sequence of plant parts in specific growth stages at specified times to complete their life cycles, some rather small differences in phenologic development rates could lead to large larval mortality rates (Embree 1965; Eidt and Cameron 1971). This hypothesis does not appear to be very attractive for the coniferophagous budworms because white spruce and black spruce both break bud at the same time, but the latter experiences much less damage (Manley and Fowler 1969). These authors also report that the species difference in budworm damage appears to be inherited. Even if asynchorous bud opening were involved, it might not be an important source of resistance because the newly emerged larvae can apparently mine last year's needles until the buds have developed to the proper stage (McGugan 1954; Atwood 1944).

CONCLUSIONS

Even though an early instar larvae of a *Choristoneura* species could be made to successfully feed on any conifer, there probably are some clear host preferences that have their basis in a mechanism other than "imprinting." From a resistance breeding standpoint it is very important to know how these preferences are being expressed. For example, if the green trees are the result of inheritance of a feeding deterrent or the absence of a feeding excitant, breeding for resistance would be a simple, straightforward matter. East-to-use classic pest screening methods could be employed.

But if the green trees derive from any integration with the chemical message system of the insect, considerable knowledge would have to be gained even before breeding and testing procedures could be planned. Conceivably, very subtle variations in the chemical message system between plant and insect could account for the green trees. Some possible mechanisms suggested by Hendry and others (1976) are production of too little or too much sex attractant, and subtle plant chemistry shifts during a growing season. Such mechanisms would greatly complicate development and deployment of resistance, but at the same time they should provide a wider range of management alternatives and the possibility of stable managed ecosystems.

If some kind of predator or parasite interaction is involved, classical progeny tests could be erratic or lead to negative results. On the other hand, it might be possible to screen Douglas-fir progenies chemically for known kairomones. This avenue deserves further attention.

Details of a screening program will be controlled to a great extent by the nature of the budworm-Douglas-fir interaction. Both phenotypic variation in degree of defoliation and ready explanations for the condition exist. In the event that classic progeny tests fail to provide positive results, an attractive alternative hypothesis, in light of available evidence from the literature is the oak leaf roller scenerio. If this hypothesis is true then progeny testing based on presentation of host materials to unfed stage II larvae would probably not show any differential feeding preferences, and knowledge of the influence of parental food on larval food preference would become critical.

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INT-307

March 1981

Effects of Sheep Grazing on a Riparian-Stream Environment

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Research Note
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March 1981

Effects of Sheep Grazing on a Riparian-Stream Environment

William S. Platts[1]

ABSTRACT

A stream section in a meadow receiving high intensity 'razing from sheep was almost five times as wide and only ıne-fifth as deep (average) as an adjoining stream section /here the meadow received light or no grazing. In the 'eavily grazed area, undercut banks were eliminated, treambanks were outsloped, and water depth at the tream surface-stream channel interface was only one-hirteenth as deep as in the lightly or nongrazed area. To old sheep on meadows for long periods of time is probably 'etrimental to the riparian-stream ecosystem.

KEYWORDS: streamside vegetation, fishery, stream morphology, streambank erosion.

A valid assessment of the result of sheep grazing on parian-stream habitats is not possible because of the lack f quantitative data for evaluation (Meehan and Platts 978). Some data are available which describe the effects n stream ecology of cattle grazing (Platts 1978a, 1978b), ut only rough, subjective information that describes the ffects of sheep grazing on aquatic ecosystems is available.

When evaluating the effects of livestock grazing on treams, it must be recognized that different classes of vestock graze the watershed in different ways. Sheep re often classified as grazers that use slopes and upland reas, while cattle are usually thought of as grazers that ave more tendency to use the lesser slopes or bottom-ınds which usually include riparian habitats. Because heep grazing on public lands is usually controlled by erding, it is possible to graze a watershed without xerting significant influences on riparian habitats. This tuation appears to be the case in my study sites (fig. 1) n Frenchman Creek in the Sawtooth National Recreation rea, Idaho, where sheep are herded and managed under deferred rotation system. In the nearby Pole Creek study te, however, also under a deferred system, past driveway se has put additional heavy grazing pressure on the parian and stream environments. The traditional heavy se has been from driveway sheep using the meadows ır forage and bedding while awaiting shipment.

This report quantitatively describes the changes in a riparian-stream system in the Pole Creek meadows under this sheep-holding grazing strategy. A future report will compare this type of grazing strategy to a herding-deferred rotation-grazing strategy now being used on the Frenchman Creek study sites.

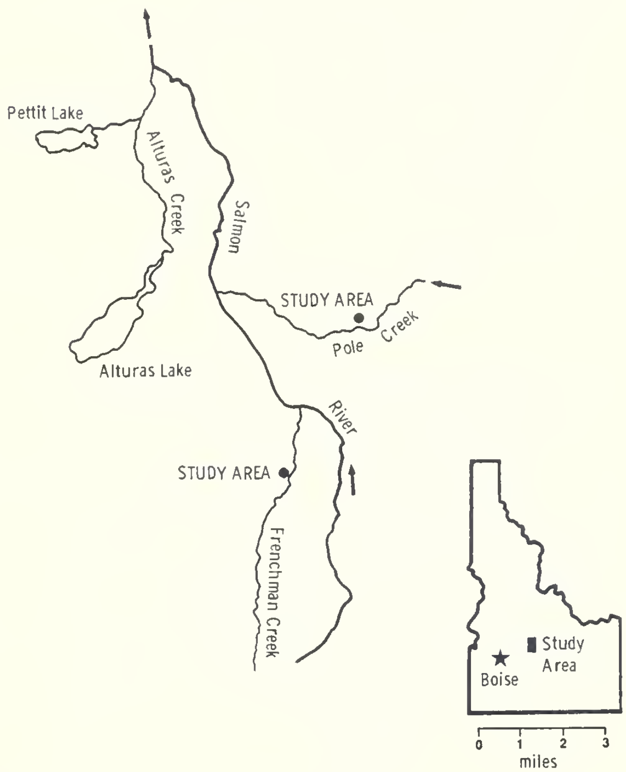


Figure 1.--Study Area locations.

[1]Research fishery biologist, located at the Intermountain Station's Forestry Sciences Laboratory, Boise, Idaho.

STUDY AREA

The study was conducted in the Pole Creek drainage in the headwaters of the Salmon River drainage in Idaho. This river supports most of the chinook salmon (*Oncorhynchus tshawytscha* [Walbaum]) and steelhead rainbow trout (*Salmo gairdneri* Richardson) that enter Idaho to spawn. Waters in the Salmon River drainage are usually low in mineral content because of the predominance of granitic bedrock. The study site is on a small spring-fed stream; a tributary to Pole Creek, at 6,200 feet (1 890 m) elevation, that flows in meadows formed by extensive Pleistocene glacial deposits. The sediment forming the meadows was transported from higher elevations by glaciers and deposited as an outwash train. Subsequently, the streams passing through the meadows have reworked the sediment and evolved the meadows to their present morphology in quasi-equilibrium with climatic change.

The study stream has a gravel bottom with lesser amounts of rubble and fine sediments. Small numbers of brook trout (*Salvelinus fontinalis* [Mitchill]), sculpin (*Cottus* spp.), and possibly rainbow trout occupy the stream. Because of the stream's small size, fish numbers per unit of stream length are low; brook trout average only one per 100 ft (30.5 m) of stream.

GRAZING HISTORY

Prior to European man entering the Salmon River drainage, the study site was grazed mainly by wild ungulates, rodents, and insects. Upon settlement of the Snake River Plain, the white man quickly recognized the possibility of using the rangelands in the Idaho batholith for summer forage. As a result, the number of livestock brought into the Upper Salmon River drainage for summer forage quickly increased. During the late 1800's the use was predominantly sheep, with cattle entering in the early 1900's to graze the lower elevation pastures. Since the late 1800's, the Pole Creek drainage has been grazed primarily by sheep with minor grazing by domestic horses.

By the late 1800's and early 1900's, sheep numbers grazing the Pole Creek meadows had mushroomed because the area was on the Ketchum-Stanley sheep driveway. William Horton, District Ranger at the Pole Creek Station, reported in 1910 that 200,000 sheep were using the sheep driveway each year. The bands of sheep that historically used the Pole Creek meadows exerted more grazing pressure on the riparian-stream environment than was normally found under the most commonly used sheep grazing strategies.

In 1910, a 30-acre (12.2-hectare) section of Pole Creek meadows was fenced and used as a Forest Service Guard Station (fig. 2 and 3). Thus, sheep were restricted from grazing the administrative site (Guard Station), but heavy grazing continued in the remainder of the meadow until the mid-1960's when sheep numbers began to decline. In 1910, Ranger Horton reported that inside the fenced ungrazed area, pine and fir seedlings had excellent survival, while outside the fenced site there was little or no survival. By 1934, the meadow adjacent to the fenced area received such heavy use that 150 acres (60.7 hectares) had to be reseeded. From 1959 to 1975, the meadow continued to receive heavy use for sheep forage and bedground. The USDA Forest Service took action in 1964 to close the sheep driveway from Ketchum to Stanley to spring travel. That action resulted in much less grazing pressure on the meadows.

The fence around the guard station was not entirely effective in keeping out all sheep. In 1936, it had to be reconstructed to further exclude sheep grazing. From 1964 to 1974, 10 horses and mules were grazed in the fenced area for about 1 month each summer. Throughout recent years, however, grazing within the fenced area was low and had an insignificant effect on most of the stream within the fenced portion of the meadows.

The past annual heavy sheep grazing on the meadows compared to the light or nonexistent grazing of recent years provides an ideal example by which we can quantify riparian and stream reactions to heavy sheep grazing.

Figure 2.--The lay-down fence separating the heavily grazed area from the lightly grazed area. Note the wide, shallow stream in the heavily grazed area narrowing as it enters the fenced area.

Figure 3.--Looking from the fenced lightly grazed area into the heavily grazed area. Note the narrowness of the stream in the lightly grazed area.

METHODS

To determine riparian and aquatic habitat conditions, a group of 121 channel cross sections were located within the study site. The cross sections were at 10-ft (3.05 m) intervals covering 600 ft (182.9 m) of stream in the lightly grazed area immediately downstream from the fence separating the two areas, and 600 ft (182.9 m) of stream immediately upstream from the fence in the heavily grazed area (fig. 4). Cross sections ran from bank to bank, perpendicular to the main flow of the stream. Aquatic habitat measurements were taken in July, August, and September; and riparian measurements were taken in October after the grazing season had ended.

The following environmental conditions were evaluated:

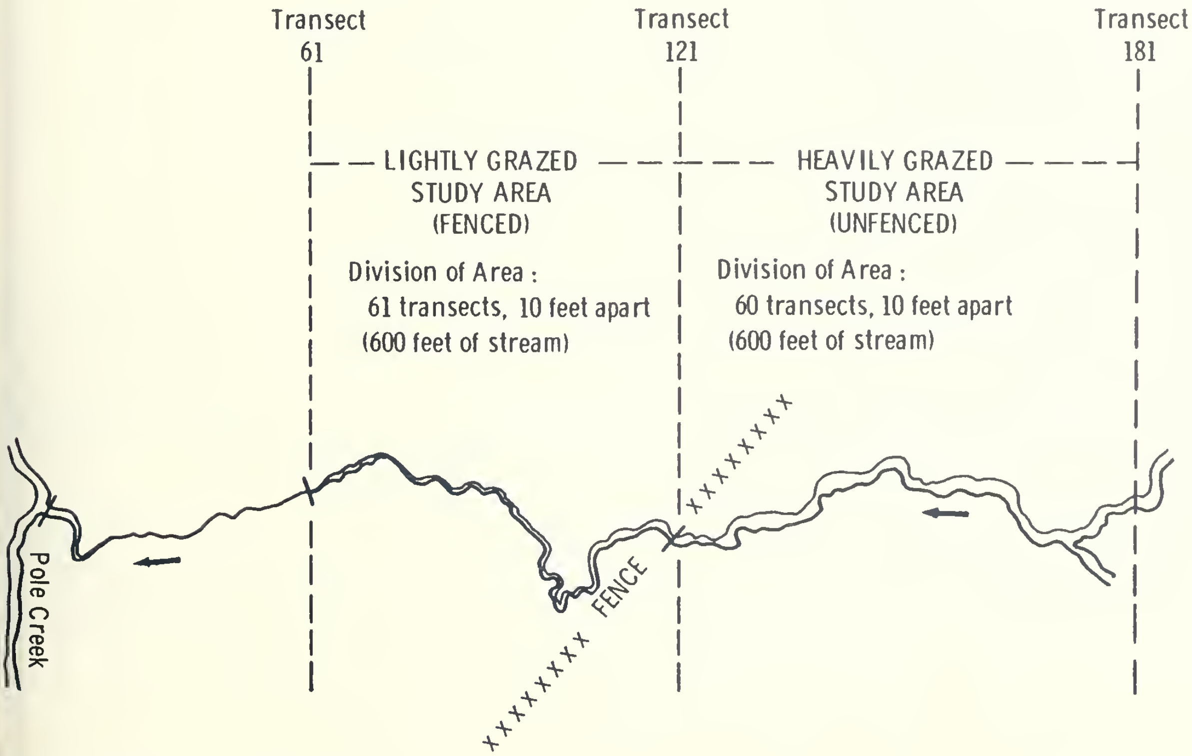
1. Stream channel materials
2. In-stream vegetative cover
3. Substrate embeddedness
4. Channel gradient
5. Stream width and depth
6. Bank-stream contact water depth
7. Pool area and quality
8. Riffle area
9. Streambank alteration
10. Streambank rock content
11. Steambank angle
12. Streamside vegetation
13. Streamside cover stability
14. Vegetative overhang
15. Stream channel profile
16. Stream velocities
17. Streambank undercut

A brief summary of the procedures used in this study follows. A more detailed description of the methodology used appears in Platts (1974), Platts (1976), and Ray and Megahan (1978).

Stream Channel

Channel materials were classified into five classes by visually projecting each 1-foot (0.305-m) division of a measuring tape to the streambed surface and assigning the major observed sediment class to each division. Sediments were classified as: large boulder, 24 inches (610 mm) or larger in particle diameter; small boulder, 12 to 23.9 inches (305 to 609 mm); rubble, 3 to 11.9 inches (76 to 305 mm); gravel, 0.19 to 2.9 inches (4.8 to 76 mm); and fine sediment, less than 0.19 inch (4.8 mm) in particle diameter.

In-stream vegetative cover was a direct measurement of the vegetative cover on the channel intercepted by the transect. Stream channel substrate embeddedness measured the gasket effect of fine sediment around the larger size substrate particles. The rating ranged from a high of 5 (less than 5 percent of the larger substrate covered or contacted by fine sediments) to a low of 1 (over 75 percent of the larger substrate covered with fine sediment). Channel gradient was taken at each transect using an engineer's level and sighting rod.



gure 4.--Sketch of study site.

Water Column

Stream width was a horizontal measurement of that area of the transect covered by water. Stream depth was the average of four water depths taken at selected intervals across the transect from the water surface to the channel bottom. Water depth at the intersection of the streambank or stream channel with the edge of water was a direct measurement from water surface to channel bottom. Pools were classified as that area of the water column usually deeper than riffles and slower in water velocity. The remainder of the water column was designated "riffle." Pool quality rating was based on the pool's ability to provide certain rearing requirements needed by fish. A top quality pool rated 5 (over 3 feet [0.91 m] deep or over 2 feet [0.61 m] deep with abundant fish cover) and a poor quality pool rated 1 (shallow and small with little cover).

Streambanks

Streambank alteration reflected the quantity of natural and artificial change occurring to the streambank and was ranked from zero to 100 percent. Streambank rock content provided a measure of the percentage of rock in the streambank over 0.19 inch (4.7 mm) in particle size. The streambank angle was measured with a clinometer, which determined the downward slope of the streambank to the water. Streambank undercut was a direct horizontal measurement, parallel to the stream channel, of the erosion of the bank at the water influence area.

Riparian Vegetation

Streamside cover was categorized according to the dominant vegetation as "tree," "brush," "grass," or "exposed." Streamside cover stability was a four-group rating of the ability of the cover on the streambanks to keep water flows from eroding streambanks. A rating of 4 is excellent (over 80 percent of the streambank is covered by vegetation in vigorous condition preventing erosion), and a rating of 1 is poor (less than 25 percent of the streambank is covered by vegetation with little erosion control). Vegetative overhang directly measured the length of the vegetation overhanging the water column within 12 inches (0.301m) of the water surface.

Hydrologic Geometry

An engineer's level and measuring rod were used to profile the cross sections. Twenty of the 121 cross sections, 10 in each study site, were selected to represent the study area. A sag tape was stretched across the transect and from this tape, vertical and respective horizontal measurements were made across the transect from the tape to the streambank, stream channel, and water level. Using a sag tape program developed by Ray and Megahan (1978), a computer was used to plot cross sections. Water velocities were taken at selected intervals across the transect.

RESULTS

Geomorphic

WATER COLUMN

Significant differences occurred in stream width and depth between the fenced (lightly grazed) and unfenced (heavily grazed) study areas (table 1). Stream width was over four times as wide in the heavily grazed area as in the lightly grazed area. Sheep use on the streambanks in the heavily grazed meadow caused the banks to erode away from the water column; so over four times as much surface was exposed to solar radiation in the heavily grazed meadow versus the lightly grazed meadow.

Average stream depth was almost five times as great in the lightly grazed area as in the heavily grazed area. The depth of the stream at its interface with the streambank or stream channel was almost 13 times as great in the lightly grazed meadow as in the heavily grazed meadow.

Percent riffle and percent pool were not significantly different between the sites. Mean pool quality was slightly higher in the lightly grazed area than in the heavily grazed area, but not significantly. Mean stream velocity was higher in the lightly grazed area than the heavily grazed area, but the significance was at the 90 percent level.

Table 1 **A comparison of variable means and their 95 percent confidence intervals between the lightly grazed and heavily grazed sites**

	Area			
	Fenced		Unfenced	
Item	**Mean**	**Interval**	**Mean**	**Interval**
Water column				
Stream width (ft)	1.8	1.3- 2.3	7.8	7.3- 8.3
Stream depth (in)	6.2	5 7- 6.6	1.3	.9- 1.7
Riffle (percent)	83.3	76.2- 90 4	85 2	78.1- 92.3
Pool (percent)	16.7	9 6- 23.8	14.8	7.7- 21.9
Pool quality	1 9	1 4- 2 4	1.5	1.1- 1.9
Bank water depth (in)	5.1	4.5- 5.8	4'	.0- 1.1
Stream velocity (cfs)	1 3	1 0- 1 5	.8	.7- 1.0
Channel				
Embeddedness	3 2	2.9- 3.5	4.8	4.6- 5.1
Boulder (percent)	.0	-	.0	-
Rubble (percent)	2.5	0- 7.2	0	-
Gravel (percent)	69.3	61.0- 77.0	98 2	90.0- 100.0
Fines (percent)	5.3	1.5- 9 1	1 2	.0- 5.0
In-stream vegetative cover	2	.0- 4	.5	.3- .7
Gradient (percent)	.7	-	1 2	-
Streambanks				
Bank angle (degrees)	82.0	75.0- 90.0	132.0	125.0- 140.0
Bank undercut (in)	1.7	1.3- 2.1	.6	.2- 1.0
Streambank alteration natural	3.5	2.1- 4 9	5.8	4 4- 7.1
Streambank alteration artificial	5.7	1 4- 9.9	86.1	81 9- 90.4
Vegetative cover type	2.1	2.0- 2.2	1.9	1.9- 2.0
Bank stability	3.9	3 9- 4 1	3.8	3.8- 3.9
Vegetative overhang	6.9	6.1- 7.8	7.3	6.7- 8 4
Vegetative use	2.3	.0- 5.0	37.3	34.6- 20.8
Habitat type	17.7	17.7- 18.2	14.0	13.4- 14 7
Streambank rock content	1.0	1.0- 1 0	1.0	1.0- 1.0

STREAM CHANNEL

Percent gravel in the stream channel was significantly higher in the heavily grazed area than in the lightly grazed area. Channel rubble was lacking in the heavily grazed area and almost lacking in the lightly grazed area. There was no significant difference in fine sediments, and boulder material did not appear in any of the areas. Fine sediments in the channel had a higher gasket effect (embeddedness) around the gravels in the lightly grazed area than they did in the heavily grazed area.

Because of the much wider stream channel in the heavily grazed area, there was about twice as much in-stream vegetation covering the stream channel in the heavily grazed area as in the lightly grazed area. Percentagewise, however, in-stream vegetative cover was higher in the lightly grazed area. Mean channel gradient was higher in the heavily grazed area.

STREAMBANKS

Streambanks in the heavily grazed area were modified from their natural condition by the high utilization of forage. The streambanks were eroded away from the water column, outsloped, and had little undercut bank (overhang bank) (fig. 5 and 6). The angle the bank made with the channel was much higher in the heavily grazed pasture, the lightly grazed area had about three times as much underuct in the streambanks.

Natural streambank alteration was about the same for both areas. But, streambank alteration was about 15 times greater in the area heavily grazed in the past than in the area lightly grazed.

Measurements showed no difference between areas in bank stability, which is a rating of the vegetative cover and of the erodibility of the banks. This validates the observation that as the banks are eroded away and become setback and increasingly sloped, the widened channel accepts most of the stream flow energy and vegetation is continually established as the banks are eroded and cut back. Streambank rock content ratings showed streambanks in both areas were composed mainly of fine sediments. No significant differences were noted between areas for vegetative cover types and vegetative overhang. The difference, however, in percent of water surface covered by vegetative overhang was large. The percent of surface covered was higher in the fenced area. Vegetative use, of course, was high in the heavily grazed area. But, use was higher than expected in the lightly grazed area because of a few sheep were able to pass through the fence and graze the fenced meadow area in 1978.

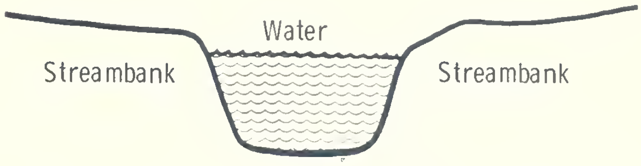


Figure 5.--Typical stream channel cross section in the lightly grazed site.

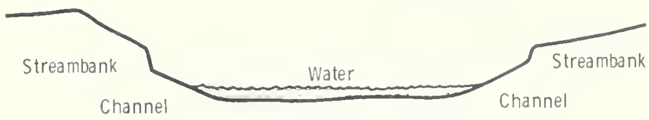


Figure 6.--Typical stream channel cross section in the heavily grazed pasture.

Habitat condition is a rating of the cover or lack of cover on the streambank. Theoretically, the higher the habitat condition rating the more favorable the streambank would be for fish. The habitat condition rating was significantly higher in the lightly grazed area.

Cross Sections

Channel cross sections exemplify conditions that the data in table 1 indicate (fig. 5 and 6). Channels in the heavily grazed area have widened, streambanks have been set back, stream depth has been greatly reduced, more surface area has been exposed to solar radiation, and water depth at the water surface-channel interface has been reduced. The changes occurred over a long period and it may take an even longer time for the stream to revert to its natural condition.

DISCUSSION

Sheep are often said to prefer slopes and upland areas for grazing; so, under proper management, they would be expected to have little onsite effect on riparian-stream environments. This study shows, however, that when sheep are forced to concentrate on riparian-stream areas they adversely affect these environments. Heavy, concentrated sheep grazing can make streams wider and shallower, can increase the slope of streambanks, eliminate undercut banks, change riparian habitat type, expose the stream to more solar radiation, and decrease water depths at the stream surface-streambank interface.

The study stream was small and did not carry a sufficient fish population for analysis; so this report does not say whether these changes are good or bad for fish. Only 18 brook trout and fewer sculpin occurred in the 1,620 feet (493 m) of stream sampled. Fishery biologists generally agree, however, that the documented changes do tend to decrease fish populations (Duff in press; Marcuson 1977). Therefore, to concentrate sheep on meadows for long periods would be detrimental to the riparian-stream ecosystem. Under a grazing strategy, such as deferred use combined with good herding, there would be fewer harmful effects. The present management of sheep on Pole Creek meadows is considerably better than that used in the past. Our ongoing studies will determine the effect of these better management practices on riparian-stream systems.

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Paired Comparisons: A Method For Ranking Mule Deer Preference For Various Browse Species

Susan M. White and Bruce L. Welch[1]

ABSTRACT

Ten browse species were ranked according to pref- 'rence by two tame mule deer. The statistical design vas a balanced incomplete block design, using Kendall 'oefficient of concordance to test significance.

KEYWORDS: palatability ranking, mule deer

Concern has developed in recent years for restora- ion of big game ranges disturbed by increases in urface mining and other activities (Bay 1976). <nowledge of big game preference for various browse pecies and subpopulations within species would facili- ate long term success in these restoration programs Plummer and others 1968). Various testing methods ave been used to evaluate mule deer (*Odocoileus emionus*) preference. Often such methods are time onsuming and/or show an undesirable amount of error Smith 1950; Smith 1959; Wallmo and others 1973; heehy 1975; Scholl and others 1977; Welch and IcArthur 1979; Smith and Shandruk 1979; Welch and thers in press). The purpose of this paper is to present method for rapid evaluation of mule deer preference or various winter browse species.

MATERIALS AND METHODS

In mid-January 1977, two tame deer[2] (a buck and a oe) were used to rank preference of 10 browse spe- ies. A population of each browse species to be tested vas selected from locations surrounding Provo, Utah able 1). Test samples consisted of the terminal 4 nches (10.16 cm) of current-year growth from randomly elected shrub plants, except for sweetbriar rose hips, vhich consisted of a twig and one hip.

The tame deer were fed a daily ration of alfalfa, deer pellets, and barley. Alfalfa and deer pellets were fed *ad libitum* and barley was restricted. One week prior to testing, 10 browse species from the same location where the test samples would be collected were fed daily to the deer *ad libitum*. During this pretesting, all 10 browse species were used but to different degrees. After 5:00 p.m. the day before the actual test, barley was not given out and alfalfa and the pellets were reduced to three-fourths the normal ration to assure the deer would be hungry for the trials. Testing began the following day at 9:00 a.m. During the test the deer were allowed to roam freely around the pen and had access to the alfalfa. All testing of browse species was done in one day.

The feeding trail was conducted as a balanced, incomplete block design with replication. A block consisted of presenting one of the deer with two different browse species at one time, twigs of the two browse species were held in the hands of the observer. There were 10 successive replications within each block and with each replication a new sample was used. Each browse species was compared with the other nine. this totaled 45 blocks or 450 individual comparisons; a layout of this design, as well as the research results, are presented in figure 1. Within each replication the species closest to the nose of the deer was alternated. In

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[2]The tame deer were provided by Utah State Division of Wildlife Resources Wildlife Relations Project, Logan, Utah 84321.

Table 1.—Location of populations of test species used in the paired comparison method of ranking mule deer preference for various browse species

Scientific name	Common name	City and county
Rosa eglanteria	Sweetbrier rose	Provo, Utah County
Cercocarpus ledifolius	Curlleaf mahogany	Provo, Utah County
Cowania mexicana	Cliffrose	Springville, Utah County
Purshia tridentata	Antelope bitterbrush	Springville, Utah County
Prunus virginiana	Black chokecherry	Springville, Utah County
Artemisia tridentata spp. *vaseyana*	Mountain big sagebrush	Springville, Utah County
Atriplex canescens	Fourwing saltbush	Orem, Utah County
Artemisia tridentata spp. *tridentata*	Basin big sagebrush	Indianola, Sanpete County
Chrysothamnus nauseosus	White rubber rabbitbrush	Nephi, Juab County
Cercocarpus montanus	True mountain mahogany	Nephi, Juab County

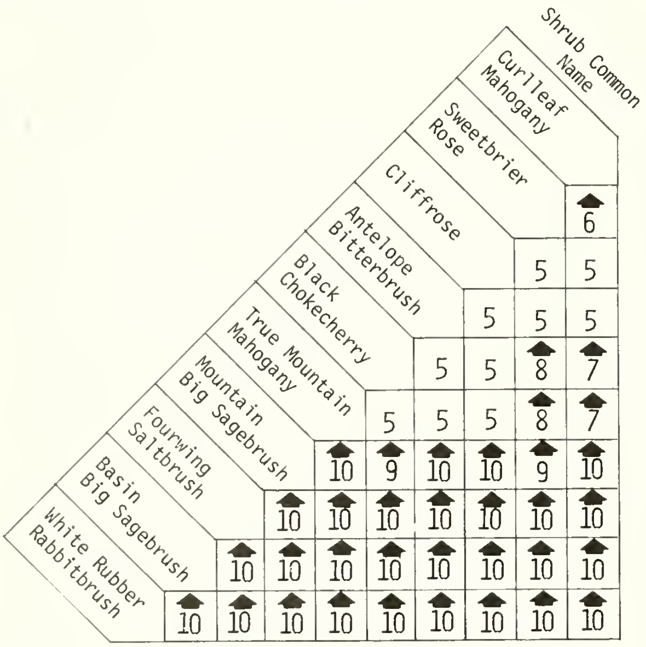

Figure 1.—Experimental design for testing 10 browse species. Each square represents 10 replications. Values in the squares are the number of times out of 10 that one member of the pair was chosen over the other. Arrows point to the pair member favored by the mule deer.

order to evaluate preference, the rank of 1 was assigned to the browse species not selected and a rank of 2 to the species selected.

This design assumes no differential preference between tame mule deer and wild mule deer. Other designs, such as the cafeteria and utilization by the bite-couting methods, make the same assumption.

Smith (1950), studying the preference of two captive wild mule deer for browse species, found that the deer preferred some browse species over others. The ranking of seven species common to ours and Smith's studies was similar (curlleaf mahogany, cliffrose, bitterbrush, chokecherry, mountain mahogany, big sagebrush, and rubber rabbitbrush).

Incomplete blocks in rank experiments make a useful experimental design for determining deer preference for various foods. The advantages of this design to others (Heady 1964): (1) less time and forage samples are needed and it eliminates error due to spilling and scattering of food by the test animals as in cafeteria design (Smith 1950; Smith 1959); (2) it eliminates the need for growing all species of interest in field plots, as in most utilization, rumen, or fecal analysis designs (Heady 1964; Sheehy 1975; Welch and McArthur 1979); (3) less technician time and training are needed compared to rumen or fecal analysis designs (Hansen and Dearden 1975; Smith and Shandruk 1979); (4) it eliminates variation among observers compared to designs based on utilization by percentage of twigs browsed (Pechanec 1936; Cole 1963; Jensen and Scotter 1977); (5) it eliminates differential availability (a weakness of utilization, rumen, or fecal analysis designs) (Heady 1964); and (6) it eliminates estimation errors common to utilization by the bite-counting method designs (Wallmo and others 1973).

Data were analyzed using a nonparametric test, that Durbin (1951) suggested for the analysis ranking of paired comparisons in an incomplete block design (Gibbons 1976); the null hypothesis was that there was no difference in the preference for the 10 species. A nonparametric test was selected because ordinal numerical data were used to rate preference. Requirements for this test: (1) each object should occur an equal number of times, and (2) the number of times two particular objects occur together in the same block should be the same for all possible pairs of objects (Durbin 1951). Following is a test of 10 treatments with Q as the test statistic. The value of W is the Kendall coefficient of concordance; this value lies between 0 and 1. The value of 0 implies no preference or *no* association between objects being tested, and the value of 1 indicates preference or perfect association.

'he value of W is computed using the formula:

$$W = \frac{12\left(\sum_{j=1}^{n} R^2 j - \frac{3k^2 m^2 (m+1)^2}{n}\right)}{\lambda^2 \, n(n^2-1)}$$

/here:

λ = the number of complete sets of paired comparisons
m = the number of ranks
n = the number of objects to be ranked
$R^2 j$ = the sum of the ranks assigned to a particular object
k = the total number of individual comparisons (In this case the above values were: $\lambda = 45$, $m = 2$, $n = 10$, $R = 188716$, and $k = 450$.)

The test statistic for this test, ϱ, follows approxi-ately the chi square distribution. The value of ϱ is sed when:

$$\varrho = \frac{\lambda (n^2-1) W}{m+1}$$

ith $n-1$ degrees of freedom. If the null hypothesis is ejected, then a multiple comparison procedure can be sed to see which treatments differ significantly from ach other using the interval:

$$|Ri - Rj| \leq Z \frac{\sqrt{n \lambda (m+1)}}{6}$$

he value of Z if found from the normal curve, which orresponds to the right-tailed probability of $\alpha / n(n-1)$.

RESULTS AND DISCUSSION

Results of the preference ranking experiment showed that the tame mule deer significantly preferred some of the browse species over others ($W = 0.78$, $\varrho = 258.6$, $\alpha = 0.000$). Curlleaf mahogany and hips of sweetbriar rose were the most preferred, and white rubber rabbitbrush in our test was never chosen. Table 2 gives the ranking of all 10 browse species. (For comparison of given pairs, see fig. 1). Because genetic variation occurs in palatability with species collected from different locations (Welch and McArthur 1979; Welch and others, in press; White and others, in press), this ranking of the 10 browse species must be considered restricted to the array presented.

Table 2.—The rank position and percent of the times that mule deer chose each of the 10 browse species, in preference to the alternative

Species	Percent of time chosen[1]
Curlleaf mahogany	78
Sweetbrier rose	77
Cliffrose	72
Antelope bitterbrush	72
Black chokecherry	67
True mountain mahogany	66
Mountain big sagebrush	36
Fourwing saltbush	22
Basin big sagebrush	10
White rubber rabbitbrush	0

[1]Deer preference for species connected by the same line does not differ significantly at the 0.05 level.

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Spot Fire Distance from Isolated Sources--Extensions of a Predictive Model

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ıarch 1981

Spot Fire Distance from Isolated Sources--Extensions of a Predictive Model

Frank A. Albini[1]

ABSTRACT

This note extends a predictive model for estimating spot fire distance from burning trees (Albini, Frank A. 1979. Spot fire distance from burning trees--a predictive model. USDA For. Serv. Gen. Tech. Rep. INT-56, 73 p. Intermt. For. and Range Exp. Stn., Ogden, Utah). A formula is given for the maximum firebrand lofting height by continuous flames, such as from burning piles, jackpots of woody fuel, and so forth. This height may be used directly in the algorithm detailed in the earlier work. Also, formulas and graphs are given for estimating maximum spot fire distance when the terrain downwind of the source of firebrands is covered by vegetation of low height, bare ground, or water, rather than forest. This extension is implemented by establishing an "effective" or minimum vegetation height to be used in the formulas given in the earlier work. The effective vegetation cover height so derived depends on the firebrand initial height.

KEYWORDS: spot fire, spotting, firebrands

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[1]The author is a mechanical engineer stationed at Intermountain Station's Northern Forest Fire Laboratory, Missoula, Mont.

A predictive model for the maximum distance between a source of firebrands--a burning tree or group of trees--and a potential spot fire has been published (Albini 1979) and used as the basis for a field application procedure.[2] The model is an assemblage of six separate submodels, each for a distinct aspect of the overall process involved. The six submodels describe the following processes or phenomena:

1. The structure of a steady (time-invariant) flame that consumes the combustible pyrolyzate from the foliage of a tree or from a group of identical trees burning simultaneously that provides the aerodynamic environment for the initial lofting of a firebrand particle into a quiescent atmosphere.

2. The structure of the steady buoyant plume established by the flame in a quiescent atmosphere that provides the aerodynamic environment that lofts the particle to its ultimate height.

3. The rate at which a woody particle burns as it moves relative to the atmosphere.

4. The trajectory of an inert cylinder (a surrogate for firebrand particles of cylindrical or platelike structure) in the steady, but nonuniform, flow field of the flame and the buoyant plume above it. The predicted height as a function of time is the key result of this model.

5. The structure of the surface wind field over rough terrain--idealized as a sinusoidal elevation-versus-distance contour--that transports the firebrand from its maximum height above its burning tree origin to its downwind destination.

6. The trajectory of a burning woody cylinder in a steady, but nonuniform, wind field.

A host of assumptions is needed to complete each of the separate submodels and an additional set is needed to link them in a procedure for predicting the maximum spot fire distance. These assumptions are spelled out completely in the cited work and will not be repeated here, except for those germane to the extensions presented.

Two extensions of the procedure are offered here. The first removes the restriction that the entire firebrand lofting process is driven by the transient flame from "torching" trees. Instead, the continuous steady flame from any isolated source, such as burning piles of harvest debris, "jackpots" of heavy fuel, and so forth, may be assumed to be a potential firebrand source, described only by the height of the continuous flame. The second extension relaxes the implicit assumption that the terrain over which the firebrand particle flies is forest-covered land. Thus spotting over water, meadowland, or bare ground can be estimated, extending the scope and utility of the original procedure.

FIREBRAND LOFTING BY CONTINUOUS FLAMES

If a firebrand is lofted by the flame/plume structure from a torching tree, the particle is assumed to be lifted from the treetop at the start of the steady burning

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[2]National Wildfire Coordinating Group, 1979: Fire behavior officers' field reference. USDA For. Serv. Natl. Adv. Resour. Technol. Cent., Marana Air Park, Ariz., looseleaf.

period. The particle would continue to rise until its weight was just balanced by the aerodynamic drag exerted on it by the buoyant plume flow, were it not for the fact that the fire goes out when the fuel is consumed. When the fire goes out, the plume flow structure collapses and the demise of the vertical airflow pattern limits the height achieved by the potential firebrand. So for each particle size, there is a maximum height that can be achieved for a given "steady" flame duration.

Since larger (heavier) particles rise more slowly than do smaller ones, another competition comes into play. Small particles do not continue to burn for as long a time as large ones and so cannot fall from as great a height and still start fires. By this reasoning, there is a particle size that can be lofted to such a height that it will just be consumed upon returning to the ground. A larger particle could not be lofted that high and so would fall back sooner (hence at not so great a distance downwind), while a smaller one could be lofted higher, but would be burned up before it fell back. The particle that is just consumed as it returns to the ground thus represents the firebrand that can start a spot fire at the greatest possible distance from its origin.

The equations that express quantitatively all of the relationships outlined above are to be found in the appendices, especially B and D, of Albini (1979).

If the steady burning period for a torching tree were to be extended indefinitely, the flame/plume flow structure would be permanent and one of the steps in the process described above would be eliminated. For such a continuous flame, the height that a particle can achieve in the buoyant plume is not limited by the flame's duration; so it can be assumed to reach the ultimate height where its weight and drag force are in balance. Expressed another way, the particle will rise until the vertical gas velocity in the plume is equal to the terminal velocity of the particle falling freely in the reduced-density environment of the hot plume.

The dynamic pressure distribution in the plume is given by[3]

$$q/q_F = (8/3)\left(1 - (5/8)(z_F/z)^{5/3}\right)(z_F/z)^{2/3} \qquad \text{(B10)}$$

where

- q is the dynamic pressure
- z is height

and subscript F implies the value at the tip of the flame. From the steady flame structure model, we have

$$q_F = 0.0078 z_F \quad \text{lbf/ft}^2 \qquad \text{(A60)}$$

when z_F is measured in feet.

Equating the weight of the particle to the drag it experiences, we find the dynamic pressure, q, needed to suspend a cylindrical particle of diameter D:

$$qC_D \cdot \ell D = \rho_s g \pi D^2 \ell / 4$$

or

$$q = \rho_s g \pi D / 4C_D$$

where

---

[3]Numbered equations correspond to the equations in Albini (1979). Letters preceding the numbers identify the appendices in which the equations appear.

C_D is the drag coefficient = 1.2 (D20)

$\rho_s g$ is the weight density of the particle = 19 lbf/ft^3 (D21)

ℓ is the particle length (irrelevant)

D is the particle diameter, feet.

The maximum height from which a particle can fall and still be burning when it hits the surface is given by

$$\max(z) = 0.39 \cdot 10^5 D \quad \text{ft.} \tag{D44}$$

Using (D44) to replace D in the last equation for q and using the result, along with (A60), in (B10), we can solve for the height z from which would come the firebrand particle with the greatest potential spotting distance. From (B10) and (A60) we have

$$q = (0.0078 z_F)(8/3)\left(1 - (5/8)(z_F/z)^{5/3}\right)(z_F/z)^{2/3},$$

which must equal the needed dynamic pressure. Using the equation for q and (D44), then

$$q = (19)(\pi)(z/0.39 \cdot 10^5)/(4)(1.2).$$

Equating these two expressions for q and dividing the resulting expression by z gives an equation quadratic in the ratio $x = (z_F/z)^{5/3}$, with dimensionless numerical coefficients:

$$x(1 - 5x/8) = (3/8)(19\pi)/(4)(1.2)(0.39 \cdot 10^5)(0.0078) = 0.0153$$

or

$$x^2 - 1.6x + 0.0245 = 0.$$

From this equation we obtain one physically meaningful root which gives

$$z/z_F = x^{-3/5} = (0.0155)^{-3/5} = 12.2.$$

This general result states that the height of a continuous flame multiplied by 12.2 gives the maximum viable firebrand lofting height. This height may be used directly in the nomograph (fig. 8 in Albini, 1979) to solve for maximum spot fire distance. It is denoted by z(0) in appendix F of the cited work, where the spotting distance formula is derived.

SPOTTING OVER TERRAIN NOT FOREST-COVERED

In the development of the spotting distance model, it was necessary to integrate the equations of motion of the firebrand particle as it was borne along by the wind field. The approximations justified in that development are that the particle falls with a relative vertical velocity that decreases linearly in time, while it is carried horizontally at the local horizontal windspeed. The resulting equation for the trajectory over flat terrain can be written as

$$\frac{dx}{dz} = -\left(\frac{z(0)}{z}\right)^{1/2}\frac{u(z)}{v_o(0)} \tag{F18}$$

where

x is the horizontal (map) distance from the spot source in the direction of the prevailing wind

z is the height of the particle at distance x

z(0) is the initial firebrand height

u(z) is the x-direction (horizontal) windspeed at the height of the particle, z

$v_o(0)$ is the terminal falling velocity of the particle when it first begins to descend.

Since the terminal falling velocity at the time the particle first starts to fall is related to its size by the restriction that it still be burning at impact, it can be shown that

$$z(0) = \beta^2 v_o^2(0)/g \tag{F9}$$

where β is a dimensionless constant and g is the acceleration of gravity. Using this form in the equation for the trajectory gives:

$$\frac{dx}{dz} = -\beta u(z)/(gz)^{1/2}.$$

From this equation, we have the general form for the spot fire distance, X*, over flat terrain:

$$X^* = \beta \int_{z(u=0)}^{z(0)} u(z)/(gz)^{1/2} dz.$$

In the original formulation, the profile of horizontal windspeed with height was assumed to be of the form

$$u(z) = u_H \ln(z/z_o)/\ln(H/z_o) \tag{F14}$$

where

u_H is the windspeed at treetop height, H

z_o is the "friction length," estimated to be about 0.13H for forest-covered terrain under neutrally stable conditions.

This form leads to the equation used in the nomograph (fig. 8 in Albini 1979) for spotting distance:

$$X^* = 21.9u_H\left(\frac{H}{g}\right)^{1/2}\left\{0.362 + \left(\frac{z(0)}{H}\right)^{1/2} \frac{1}{2} \ln\left(\frac{z(0)}{H}\right)\right\}. \tag{F22}$$

Clearly it is implicit in the use of (F14) in the integral for X* that the height of the particle should not exceed the range of validity of the windspeed formula by enough to distort the result significantly. When the terrain downwind of the spot source is forest covered, the aerodynamic scale parameter called the "friction length" will be on the order of meters (Baughman and Albini 1980) and since we are concerned with atmospheric conditions of at least neutral stability, the windspeed profile of (F14) should be applicable with high reliability to at least 150 m (Thuillier and Lappe 1964; Carl, Tarbell, and Panofsky 1973). The precise role of the friction length parameter, z_o, in determining the maximum height to which the logarithmic profile is applicable is not completely clear and may, in fact, be irrelevant (Tennekes 1973). It is usually assumed that z_o serves as a length scale for the friction-dominated surface layer of the atmospheric boundary layer (Plate 1971, Maitani 1979). If one interprets the data presented in the cited sources as defining the maximum height, measured in friction lengths, of the logarithmic profile's validity, then one must conclude that the maximum height is a few thousand friction lengths, depending upon stability and other considerations.

In any case, one can readily appreciate that (F22) should overestimate the maximum spotting distance if for the value of "tree height," H, one used the height of mown grass instead. The source of the error that would be made is obviously use of an inappropriate windspeed profile. To extend the applicability of the model to situations in which the firebrand trajectory is over short grass, bare ground, or even water, we need a different description of the windspeed profile that does not exhibit the singular behavior of (F22).

Boundary-layer studies on smooth, flat plates and pipe flow studies have repeatedly confirmed (Schlichting 1968) a velocity profile for turbulent flows that is of the form

$$u(z)/u_B = (z/B)^{1/7}.$$

Here B is any distance from the wall within the variable-speed layer and u_B the flow speed at that position. This form has been found to have broad applicability in meteorological work as well (Sutton 1953; Plate 1971), although exponents other than 1/7 are often used to correlate data taken in the atmospheric boundary layer. Sutton (1953) relates the exponent to stability conditions, suggesting use of 1/7 for neutral or greater stability, while Plate (1971) graphs a relationship between the exponent and aerodynamic friction length. For very small friction lengths (1 cm and less), the suggested exponent is 0.1, rising semilogarithmically to 0.4 for a 3 m friction length. For "flat, open country," the suggested exponent shown is about 1/7. The thickness of the air layer over which the power law profile is applicable in no case is less than 270 m, according to Plate, and reaches twice this value over woodlands.

On the basis of these considerations, the power law profile with an exponent of 1/7 may be used as a replacement for the logarithmic profile whenever the height of the vegetation cover is small enough and the initial height of the firebrand is large enough that the logarithmic profile becomes suspect. This "decision point" for shifting from one windspeed profile model to another should be determined, ideally, on the basis of fidelity of the models in the situation. Yet, operationally, it makes no difference whether or not the windspeed profile model employed gives an accurate description of the wind field. What matters is the spot fire distance that is predicted by the use of the windspeed model. And since both models demand a reference windspeed at a reference height from which extrapolations are made, either input variable can be adjusted artificially to provide the same prediction as would the use of the other model.

Symbolically, the spot fire distance predicted by the logarithmic windspeed profile model can be written as X_1^*, where

$$X_1^* = \beta u_H \left(z(0)/g\right)^{1/2} \left\{ \ln\left(\frac{z(0)}{H}\right) + 0.724/\left(\frac{z(0)}{H}\right)^{1/2} \right\}.$$

Likewise the spot fire distance predicted by the power law windspeed profile model can be written as X_2^*:

$$X_2^* = \beta u_B \left(z(0)/g\right)^{1/2} \left\{ \frac{14}{9} \left(\frac{z(0)}{B}\right)^{1/7} \right\}.$$

Taking u_B to be the windspeed at the standard height, B = 20 ft (6 m), and assuming that the form X_2^* gives a valid spotting distance prediction, we can discover at what value of z(0) the log formula overpredicts for a given value of H, once we assign the value of u_H. We do this by equating X_1^* to X_2^* and solving the resulting expression for z(0)/B as a function of z(0)/H and u_H/u_B. For a fixed value of u_H/u_B, inserting an assumed value for z(0)/H gives the value of z(0)/B and hence the pair (z(0),H). The graphs shown in figure 1 are plots of this relationship for different values of the windspeed ratio u_H/u_B.

Of particular interest in figure 1 is the curve for u_H/u_B = 2/3. This is the value that is assumed for this ratio in the current version of the Fire Behavior Officers' (FBO) Field Reference (see footnote 1). Consequently, when the material in that field guide is used to estimate spotting distance, the log formula will overpredict when the firebrand height is greater (for a given cover height) than the value read from that curve. Switching to the power law profile *at* that height renders the prediction then insensitive to the vegetation cover height.

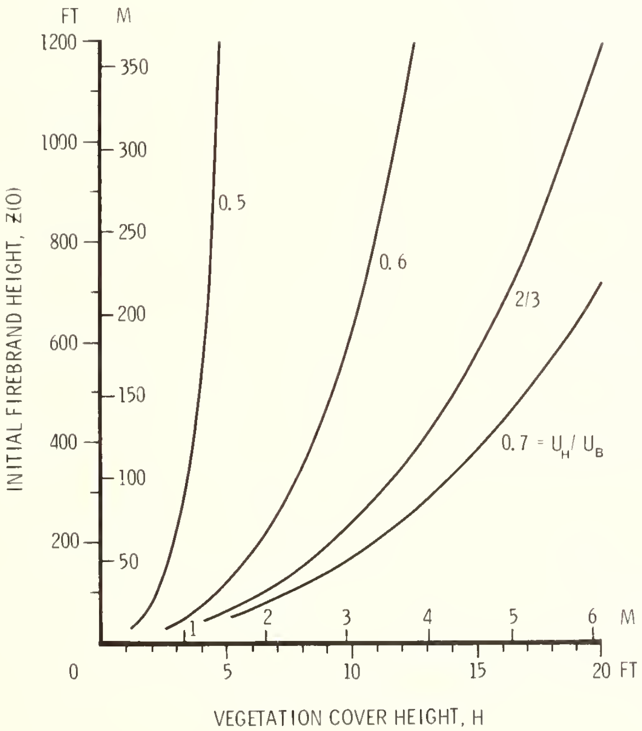

Figure 1--Decision curves for choice of windspeed profile model. Above appropriate curve, use power law model; below, use log profile. u_B is 20 ft (6 m) windspeed, u_H is windspeed used to represent value at height of top of vegetation cover.

Operationally, one need never employ the power law profile explicitly. All one need do is determine the minimum vegetation height (for a given firebrand height) required to use the log profile--by reading the graph of figure 1 "backward"--and, if necessary, to use this minimum value as an "effective" height, H*, in the log formula. In the case of the FBO Field Reference assumption, $u_H/u_B = 2/3$, the curve in figure 1 is well approximated by a simple power law relationship:

$$H^* = \begin{cases} 2.2z(0)^{0.337} - 4.0 & \text{ft, } z(0) \text{ in feet} \\ z(0)^{0.337} - 1.22 & \text{m, } z(0) \text{ in meters.} \end{cases}$$

This relationship directly gives H* as a function of z(0), as needed for the substitution. If the actual vegetation cover height is less than this value, one should merely use the "effective" value from this formula in the nomograph (or manual) calculations using the log profile formula. The obvious reason is that this "effective" value of H is just the one that will cause the log profile formula to yield the spotting distance that would be found from the power-law formula for the value of z(0) used.

The equations given in Albini (1979) for adjusting the spot fire distance in flat terrain to predict the distance in high-relief terrain are not affected by the shift in windspeed profile models. Once the flat-terrain spotting distance is predicted, it can be adjusted for terrain relief by the method outlined in the cited paper.[4]

The adjustment of spotting distance for the effect of terrain relief is included in a pocket calculator program (Chase 1981) that automates the computation of spotting distance outlined in Albini (1979). The extensions presented in this note are also included in the pocket calculator program.

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[4]There is a typographical error in Albini (1979), page 72. The "ridgetop" value of the parameter mX_1 listed on that page *should* be $\pi/2$, not π.

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Stand Estimates of Biomass and Growth in Pinyon-Juniper Woodlands in Nevada

Richard O. Meeuwig and Stephen V. Cooper[1]

ABSTRACT

Regression equations for estimating overstory biomass, fuelwood, and growth in pinyon-juniper stands are presented. Input variables are canopy cover and weighted mean height, stem diameter, crown diameter, and radial growth. Point sampling techniques for evaluating the input variables are described.

KEYWORDS: pinyon, juniper, biomass, growth, sampling methods, regression models.

Meeuwig and Budy (1981) described procedures for estimating various biomass components and growth rates in pinyon-juniper stands using point and line-intersect sampling. These procedures are much more efficient than fixed-size-plot sampling, but their theoretical basis is not readily comprehended. The purpose of this paper is to present a point sampling method for estimating overstory biomass, fuelwood, and growth that is simpler and more easily understood.

In this method, individual tree estimates are not made. Instead, the estimates are made on a stand basis, using canopy cover, mean tree height, mean diameter of stems, mean diameter of crowns, and mean width of growth rings.

All measurements and estimates in this paper apply only to singleleaf pinyon *(Pinus monophylla)* and to Utah juniper *(Juniperus osteosperma)* trees at least 10 feet (3 m) tall. Trees less than 10 feet tall are considered understory and are excluded along with such associated woody species as curlleaf mountain mahogany *(Cercocarpus ledifolius)*.

EQUATIONS

The regression equations for these stand estimates were derived from data collected in 114 stands across Nevada and in adjacent portions of California and Utah. Line-intersect sampling procedures, essentially the same as those described by Meeuwig and Budy (1981), were used in 103 stands to estimate overstory biomass, fuelwood, and growth rates. Each stand was sampled with a set of parallel lines, 98.4 feet (30 m) long and 19.7 feet (6 m) apart. Six lines were used in most stands but high-density stands were sampled with four or five lines and low-density stands were sampled with seven or eight lines. The other 11 stands were sampled with a 30 m by 30 m plot on which all trees were measured and overstory biomass, fuelwood, and growth rates were estimated with regression equations (Meeuwig 1979).

Overstory biomass is total ovendry weight per unit area of trees above stump height (6 inches or 15 cm). Fuelwood is all stems and branches larger than 3 inches (7.6 cm) diameter outside bark. Their equations in U.S. units are:

$$\hat{T} = (13.04\cdot\bar{D} - 9.585\cdot\bar{H} + 76.64\cdot\bar{D}\cdot\bar{H}\cdot\bar{C})\cdot Cov + (56.37\cdot\bar{Cj} - 88.83\cdot\bar{Dj})\cdot JCov + 1158$$

$$\hat{W} = (6.826\cdot\bar{D}\cdot\bar{H} - 22.84\cdot\bar{D} - 1.681\cdot\bar{H}\cdot\bar{C} - 0.09752\cdot\bar{D}\cdot\bar{H}\cdot\bar{C})\cdot Cov + (44.92\cdot\bar{Cj} - 67.53\cdot\bar{Dj})\cdot JCov + 177$$

where:

- $\hat{T}$ is estimated overstory biomass (ovendry pounds per acre)
- $\hat{W}$ is estimated fuelwood (ovendry pounds per acre)
- $\bar{D}$ is weighted mean stem diameter at stump height (inches)
- $\bar{H}$ is weighted mean tree height (feet)
- $\bar{C}$ is weighted mean crown diameter (feet)
- Cov is canopy cover (percent)
- $\bar{Cj}$ is weighted mean crown diameter of juniper trees only

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Dj is weighted mean stem diameter (stump height) of juniper trees

$JCov$ is canopy cover of juniper trees (percent).

Stem diameter, height, and crown diameter are all means weighted by crown area. $\bar{D}$, $\bar{H}$, $\bar{C}$, and Cov are for both pinyon and juniper, but $\bar{Dj}$, $\bar{Cj}$, and $JCov$ are for juniper only and serve as corrections for variations in species composition.

The overstory biomass equation has an R^2 of 0.993 and a standard error of estimate of 1,918 pounds per acre (2 150 kg per ha) or 2.7 percent of the mean of $\hat{T}$. The fuelwood equation has an R^2 of 0.990 and a standard error of estimate of 1,422 pounds per acre (1 594 kg per ha) or 4.6 percent of the mean of $\hat{W}$.

The equations for estimating overstory biomass growth $(\Delta\hat{T})$ and fuelwood growth $(\Delta\hat{W})$ in pounds per acre per year are:

$$\Delta\hat{T} = (17.54 - 1.745 \cdot \bar{D} + 15.76 \cdot \bar{H}/\bar{C} + 2.376 \cdot \bar{D}\bar{H}/\bar{C}) \cdot \bar{R} \cdot Cov + 19.78 \cdot \bar{Rj} \cdot JCov + 69$$

$$\Delta\hat{W} = (3.118 \cdot \bar{C} - 5.910 \cdot \bar{D} - 2.067 \cdot \bar{H} + 5.210 \cdot \bar{D} \cdot \bar{H}/\bar{C}) \cdot \bar{R} \cdot Cov + 0.4116 \cdot \bar{D} \cdot Cov - 0.2013 \cdot \bar{Dj} \cdot JCov - 8$$

$\bar{R}$ is weighted mean width of the 10 outermost complete annual rings (inches per 10 years) of pinyon and juniper trees at least 10 feet (3 m) tall. $\bar{Rj}$ is weighted mean width of the 10 outermost complete annual rings of juniper trees only. $\bar{R}$ and $\bar{Rj}$ are weighted by crown area just as $\bar{D}$, $\bar{H}$, $\bar{C}$, $\bar{Dj}$, and $\bar{Hj}$ are.

The biomass growth equation has an R^2 of 0.991 and its standard error of estimate is 32 pounds per acre (36 kg per ha) per year or 4.1 percent of the mean value of $\Delta\hat{T}$. The fuelwood growth equation has an R^2 of 0.984 and its standard error of estimate is 24 pounds per acre (27 kg per ha) per year or 4.8 percent of the mean value of $\Delta\hat{W}$.

The metric equivalents of the regression equations are:

$$\hat{T} = (5.756 \cdot \bar{D} - 35.25 \cdot \bar{H} + 33.82 \cdot \bar{D} \cdot \bar{H}/\bar{C}) \cdot Cov + (207.3 \cdot \bar{Cj} - 39.20 \cdot \bar{Dj}) \cdot JCov + 1298$$

$$\hat{W} = (9.883 \cdot \bar{D} \cdot \bar{H} - 10.08 \cdot \bar{D} - 20.28 \cdot \bar{H} \cdot \bar{C} - 0.4632 \cdot \bar{D} \cdot \bar{H} \cdot \bar{C}) \cdot Cov + (165.2 \cdot \bar{Cj} - 29.80 \cdot \bar{Dj}) \cdot JCov + 198$$

$$\Delta\hat{T} = (7.738 - 0.3031 \cdot \bar{D} + 6.956 \cdot \bar{H}/\bar{C} + 0.4127 \cdot \bar{D} \cdot \bar{H}/\bar{C}) \cdot \bar{R} \cdot Cov + 8.727 \cdot \bar{Rj} \cdot JCov + 77$$

$$\Delta\hat{W} = (4.514 \cdot \bar{C} - 1.027 \cdot \bar{D} - 2.993 \cdot \bar{H} + 0.9052 \cdot \bar{D} \cdot \bar{H}/\bar{C}) \cdot \bar{R} \cdot Cov + 0.1816 \cdot \bar{D} \cdot Cov - 0.0882 \cdot \bar{Dj} \cdot JCov - 9$$

$\bar{D}$ is in centimeters, $\bar{H}$ and $\bar{C}$ are in meters, $\bar{R}$ is centimeters per 10 years, $\hat{T}$ and $\hat{W}$ are kilograms per hectare, and $\Delta\hat{T}$ and $\Delta\hat{W}$ are kilograms per hectare per year.

POINT SAMPLING PROCEDURE

The stand parameters required for input into the regression equations can be determined in a number of ways: fixed-size-plot, line-intersect, or point sampling. A method that samples in proportion to crown area, the simplest and most efficient approach, will be described.

A grid of points is laid out in the stand to be sampled. Species, stump height diameter, height, and average crown diameter are tallied for each tree whose crown is over a sample point. If growth is to be estimated, radial growth of the tallied trees is also measured. If a point falls under the overlapping crowns of two trees, both are tallied. Only pinyon and juniper at least 10 feet tall are tallied. Daubenmire's (1959) criteria are followed in defining crown coverage. Each crown is considered a polygon of lines connecting the branch ends around the tree. Gaps between branches are considered part of the crown.

Since sampling probability of each tree in the stand is proportional to its crown area, the means of stump diameter, height, crown diameter, and radial growth are automatically weighted by crown area. The stand parameters are calculated as follows:

$$Cov = \frac{n}{N} \times 100 \qquad JCov = \frac{nj}{N} \times 100$$

$$\bar{D} = \frac{\Sigma D}{n} \qquad \bar{Dj} = \frac{\Sigma Dj}{nj}$$

$$\bar{H} = \frac{\Sigma H}{n}$$

$$\bar{C} = \frac{\Sigma C}{n} \qquad \bar{Cj} = \frac{\Sigma Cj}{nj}$$

$$\bar{R} = \frac{\Sigma R}{n} \qquad \bar{Rj} = \frac{\Sigma Rj}{nj}$$

where:

N is the number of sample points

n is the number of tallied pinyons and junipers

nj is the number of tallied junipers

D, H, C and R are the tallied tree measurements, both species

Dj, Cj, and Rj are tallied juniper measurements.

As an example, let us assume a stand is sampled with a grid of 20 points and that six pinyon and two junipers are tallied, $\bar{D}$ is 14.8 inches (37.6 cm), $\bar{H}$ is 17.3 feet (5.27 m), $\bar{C}$ is 15.1 feet (4.60 m), $\bar{Dj}$ is 27.1 inches (68.8 cm), $\bar{Cj}$ is 27.4 feet (8.35 m), $\bar{R}$ is 0.19 inches (0.48 cm) per decade, and $\bar{Rj}$ is 0.16 inches (0.41 cm) per decade.

Total cover is 40 percent and juniper cover is 10 percent. Estimated biomass $(\hat{T})$ is 45,600 pounds per acre (51 100 kg per ha), according to the regression equation. Estimated fuelwood $(\hat{W})$ is 17,900 pounds per acre (20 100 kg per ha). This is equivalent to about 9 cords per acre, since the ovendry weight of one cord is about 1 ton. Estimated biomass growth $(\Delta\hat{T})$ is 481 pounds per acre (538 kg per ha) per year and estimated fuelwood growth $(\Delta\hat{W})$ is 274 pounds per acre (307 kg per ha) per year.

MEASUREMENTS

Stem diameter outside bark (D) is measured or estimated to the nearest inch at stump height (6 inches or 15 cm above the soil surface). For trees with more than one stem at stump height, D is the diameter of a circle having the same area as the combined cross-sectional areas of the stems, or the square root of the sum of squared diameters of the individual stems:

$$D = \sqrt{D_1^2 + D_2^2 + \ldots D_n^2}$$

Tree height *(H)* and average crown diameter *(C)* are measured or estimated to the nearest foot. Average crown diameter is the diameter of a circle having the same area as the projected area of the tree crown. It is approximated by the square root of the length of the widest axis *(Cx)* of the crown times the width perpendicular *(Cy)* to the widest axis:

$$C = \sqrt{Cx \cdot Cy}$$

If estimates of growth are desired, radial growth must be measured. Radial growth *(R)* is the combined thickness of the 10 outermost complete annual rings, measured to the nearest 0.05 inch (or the nearest 0.1 cm) on increment cores taken at stump height. An increment hammer is faster and usually produces a better core than an increment borer in pinyon and juniper. Two cores from opposite sides of the stem are usually sufficient on trees with reasonably round stems up to 16 inches (40 cm) diameter at stump height. Four cores should be taken about 90 degrees apart on larger trees and on trees with badly out-of-round stems.

For trees with more than one stem at stump height, the increment cores are taken on the largest stem. Equivalent radial growth *(R)* is calculated by multiplying the measured thickness of the 10 annual rings (R_1) by the calculated equivalent diameter *(D)* and dividing by the diameter (D_1) of the stem from which the cores were taken:

$$R = R_1 \cdot D / D_1$$

It is often difficult to determine stem diameter and to obtain representative increment cores at the stump height on junipers. In many cases, it is more convenient and accurate to determine stem diameter *(Dbh)* and radial growth *(Rbh)* at breast height (4.5 feet or 1.37 m) and correct to *Dj* and *Rj* at stump height by:

$$Dj = 1.3 \cdot Dbh + 2.2$$
$$Rj = 1.3 \cdot Rbh$$

These equations apply to measurements in inches. If measurements are in centimeters the equations are the same except the intercept in the first equation is 5.6 instead of 2.2.

SAMPLING DESIGN

Stratification of the stands and the physical layout of the sampling points depend on the characteristics of the area to be inventoried and the preferences of the designer. The number of sampling points required depends on the variability and the allowable sampling error in each stratum.

We suggest that each stratum be sampled with at least three sampling units with 20 sampling points in each unit. Each sampling unit provides an estimate of biomass and fuelwood in pounds per acre. The coefficient of variation of these estimates can be used to calculate the number of additional sampling units, if any, required to be within the allowable limit. A shortcut method for determining sample size is described by Meeuwig and Budy (1981).

A MODIFIED PROCEDURE

The following variation of the point sampling procedure is more efficient than the one just described because it requires only one-fourth as many points to obtain the same intensity of sampling. In addition to trees with crowns over the sampling point, trees are tallied if their crowns are within one-half of their average crown diameter of the sampling point. This variation increases the probability of any particular tree being tallied at a random sample point by a factor of four.

Use of this variation requires only a minor change in calculation procedures. The regression equations and the calculation of mean height, stump diameter, crown diameter, and radial growth remain the same. The only difference is in the calculation of canopy cover percentage:

$$Cov = \frac{n}{4 \cdot N} \times 100 \qquad JCov = \frac{nj}{4 \cdot N} \times 100$$

The extra time required to measure the crown diameter of the occasional borderline tree and its distance from the sampling point is more than offset by the time saved by using only one quarter as many sampling points. The suggested number of points in a sampling unit can be reduced from 20 to 5. Five points with the modified procedure will, on the average, result in as many trees being tallied as 20 points will with the simple procedure.

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Stem Breakage Effect on Cone and Pollen Production in *Pinus monticola* (Dougl.)

D. O. Coffen and M. A. Bordelon[1]

ABSTRACT

Two studies in a western white pine blister rust resistance breeding arboretum/seed orchard examined the effect of stem breakage on cone and pollen production. Research was based on 4 years of data from 1,529 trees 15 to 29 years of age. Cone and pollen production were increased by breakage of the main stem in the upper crown. Top pruning may be a viable technique for stimulating flowering in seed orchards of western white pine.

KEYWORDS: cone production, pruning, *Pinus monticola*

There has been increasing interest in the use of western white pine planting stock (*Pinus monticola* Dougl.) that is resistant to the fungus *Cronartium ribicola* J. Fischer ex. Rabenh. Today a breeding arboretum/seedling seed orchard, a grafted seed orchard, and a young seedling seed orchard in Idaho produce seed for this purpose. Three other seed orchards of western white pine were established from 1971 to 1974. These orchards should begin to produce commercial quantities of seed by 1990.

The cost of cone collection depends on equipment, terrain, and personnel needed, and expenses are usually greater with increasing tree height. Thus, for economic reasons, height of orchard trees should be limited by pruning or pollarding.

Pollarding may also influence the quantity of cone and seed production. This will be an important consideration because it reduces the cost per pound of seed in the orchards. Two producing western white pine orchards in northern Idaho can benefit immediately from information on pruning. Seed orchard management policies will also be needed for newly established and future seed orchards of this species.

This study reports on the effect of stem breakage on cone and pollen production in a breeding arboretum that is currently being used to produce resistant production stock. Tree climbing to collect cones and large birds landing in succulent apical leaders were the primary causes for top breakage. Data were collected for 4 years.

LITERATURE REVIEW

Results of research on pruning and crown shaping, reported in the literature, are inconsistent. Past research suggests that pruning for cone stimulation is dependent on species, degree of pruning, timing, and individual genotypes.

Faulkner and Matthews (1961) stated that crown pruning treatments to shape the crown or limit height growth have been suggested by Scandinavian workers, but that no definite proposals had been put forward as of that time for any of the conifer tree species. Zobel,[2] reporting on his trip to Northern Europe, stated that most Swedes strongly favored pruning or rounding off trees in seed orchards, even though one man produced data showing that pruned orchards were producing much less seed at 12 years of age. In the other European countries they visited scarcely anyone favored pruning conifers.

Gansel (1978), in a pruning study, reduced cone production slightly with pruning, but noted that pruning extended the period of efficient cone collection in the orchard. He also observed that orchard insects preferred trees after pruning and remarked that if seed orchard insects had been controlled, the effects of pruning on cone production might have been quite different.

Buijtenen and Brown (1963) found that pruning mature loblolly trees was not as detrimental as pruning young trees. They reported that on mature trees, removal of the upper parts of the crown resulted in a reduction in the number of female flowers and that removal of the lower part of

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[2]Zobel, Bruce J. 1962. Observations of tree improvement work in Northern Europe of interest to the southern pine region of the United Staes. North Carolina State Univ. Sch. For. Mimeo.

the crown reduced the number of male flowers. They also reported an increase in the number of female flowers in the trees from which the lower half of the crown was removed. They reported that even light pruning treatments on young trees seriously reduced the number of flowers.

Goddard and others[3] reported that light pruning had no effect on cone production of slash pine, but that medium and heavy pruning significantly reduced cone production. They felt that light pruning could be repeated periodically without production losses. They also experimented with bending the trees. Significantly more cones were produced on all bent trees and several unproductive clones flowered when bent.

Vanhaverbeke and Barber (1961) reported negative results for a branch bending experiment with slash pine. They observed 50 percent less growth on the bent branches, but there was no increase or decrease in flowering. The lower branches were more affected than the upper ones.

Zobel and others (1958), in discussing seed orchard management, stated that there were not enough data at that time to recommend pruning, but that observations of severely topped trees, such as those under power lines, showed that the lower limbs of pines can provide heavy cone crops.

Fowler (1965) suggested that manipulation of the crown shape of trees in clonal or seedling seed orchards will result in an increase in the proportion of self-fertilized seeds produced by the orchards. He used marker genes to estimate natural self-fertilization in three open-grown *Pinus banksiana* trees. He estimated that 13 percent of the seeds obtained from the upper crowns and 26 percent of those from the lower crowns resulted from self-fertilization. He reasoned that the reduction in height would reduce the distance between male and female flowers and so increase self-fertilization.

Buijtenen (1968) stated that all pruning treatments reduced the number of flowers produced in loblolly; therefore, they have discontinued further experiments on effects of pruning. Their pruning treatments were relatively severe, however, as were those of the other preceding experiments. Their lightest pruning treatment was the removal of the main leader of the last flush of growth from all major limbs and the main bole during the fall of each year.

Busse (1924) found that flower and seed production were stimulated in *Pinus sylvestris* by breaking off the leader and side branch tips on 17-year-old trees.

Wareing (1952) found that removal of the terminal bud on the side branches of Scotch pine stimulated the bud development on the uppermost "dwarf shoots." The buds thus stimulated produced male flowers on young (12 year old) trees which had not yet started flowering.

Chiba (1965) found that cutting back green shoots of *Pinus strobus* promoted the development of long shoots from resting buds. These shoots produced numerous male flowers, but few female strobili. He also reported that clonal differences in flower production were very marked.

Faulkner (1966) reported that removal of one-half of the previous year's growth, of the terminal and top fourth, fifth, and sixth whorls of laterals in April, increased the number of female flowers on Scotch pine.

Because of increasing difficulty in collecting cones from taller trees in the Tallaganda, New South Wales, *P. radiata* seed orchard, two blocks of trees were pollarded by Matheson (1976) at about 26 feet (8 m) in late 1970. The 1974 seed crop from these blocks was almost twice that of other blocks in the orchard. Pruning at an early age did not show any clear benefits in *P. radiata.* Pollarding has not only extended the productive life of the orchard, but may have also increased its average annual production.

In pruning grafted Douglas-fir, Copes (1973) suggested that ramets be permitted to grow at least 15 to 20 feet (4.6 to 6.1 m) tall before annual or every-other-year pruning is started. He also found the number of cones produced per foot (0.3 m) of tree height was nearly the same for both pruned and unpruned trees.

Melchoir and Heitmuller (1961) found that shortening the leading and side shoots of 3-year-old grafts of Scotch pine increased female or male flowering according to different clones treated. There was a great correspondence between the flowering habit of the progenies of grafts of 110 to 130-year-old trees. Pruning the side and leading shoots in February was most favorable for increasing male flowering.

MATERIALS AND METHODS

This paper presents the results of two studies conducted in the Moscow, Idaho, breeding arboretum/seed orchard. The initial research investigated the difference in cone production between top-damaged and straight-stemmed trees from data of two cone crops. A more comprehensive study on cone and pollen production of stem-damaged and nondamaged trees was initiated a year later and utilizes 4 years of data on cone and pollen production.

The first study examined 164 trees, 82 having stem damage to the last three years of growth and 82 trees displaying straight stem form. Sample trees were chosen at random from 693 trees in the orchard. Orchard trees studied were 21 to 24 years of age in 1976. An equal number of trees by age class were included in each sample group. Cone production data were obtained for each tree in the orchard by ground observation.

In the second study, observations were made on 1,44[illegible] cone producing trees. Actual counts were made of total cones. A pollen production judgment was recorded by class, that is, 0 = no pollen, light = 33 percent of capability, medium = 66 percent of capability, heavy = 100 percent of capability. Trees in this study area were from two age classes. The younger trees were 15 to 18 years old and the older trees were 24 to 29 years of age in 1979. Tree breakage, as represented by a fork in the bole, was evaluated on each tree and classed according to the position of the fork in the tree (fig. 1-4). Rankings were: 0 = no forks (fig. 1 and 3), 1 = forked at the ground (fig. 1), 2 = forked at 5 feet (1.5 m) (fig. 2), 3 = forked at 10 feet (3 m), 4 = forked at 15 feet (4.6 m), 5 = forked at 20 feet (6.1 m) (fig. 3), 6 = forked at 30 feet (9.1 m) (fig. 4).

[3]Goddard, R.E., R.K. Strickland, and W.J. Peters. 1964. 6th Prog. Rep., Coop. For. Genet. Res. Prog., Univ. Florida Res. Rep. 10.

Figure 1.--White pine forked at ground level, rank 1. No fork, rank 0 in the background left.

Figure 2.--White pine forked at 1.5 meters, rank 2.

Figure 3.--White pine (from left to right), no fork rank 0, forked at 4.5 meters rank 4, multiple fork and forked at 6 meters rank 5.

Figure 4.--White pine forked at 9 meters, rank 6.

The study area consists of a 20-acre (8-ha) breeding arboretum that is also being used as a seedling seed orchard by the USDA Forest Service, Intermountain Forest and Range Experiment Station in Moscow, Idaho. This area is located on agricultural land in the Palouse Hills, approximately one-half mile west of Moscow. The site is considerably windier, drier, and warmer than the native habitat of western white pine. Soils in the arboretum are loessal and deep. Spacing of trees is approximately 20 by 20 feet (6.1 by 6.1 m). Watering has been by sprinkler irrigation. In 1977, the orchard was fertilized with processed sewage effluents. Ground cover was controlled originally by black plastic around each tree. Later, machine mowing and horses were used for turf control.

RESULTS AND CONCLUSIONS

The first study showed that there was a highly significant difference in cone production between stem-damaged and nondamaged trees. Average cone production in 1976 was 16.1 for straight formed trees compared with 30.7 for individuals having apical stem damage in the upper crown. Similar results were evident from 1977 cone production data (table 1).

In the second study, a significant difference in cone production was found between trees having forks in the upper crown and those having no forks (table 2 and fig. 5). Tree age and height were also significant factors influencing cone production. Trees in the younger age class were more responsive to pruning. Forking in the bole above 15 feet (4.6 m) from the ground significantly increased cone production over the 4-year period. For trees forked above 15 feet (4.6 m), predicted cone increase was 376 percent more than the average value for single stemmed trees in age group 15 to 18. For trees 24 to 29 years old the predicted

Table 1.--Analysis of variance of cone crop of western white pine trees having straight stem form and trees with central stem damage

Source of variation	Analysis of variance: df	SS	MS	F
1976				
Among treatments	1	9,084.2	9,084.2	[1]15.4
Within treatments	163	96,454.8	588.1	
1977				
Among treatments	1	11,824.1	11,824.1	[1]9.3
Within treatments	163	206,658.8	1,260.1	

[1]Significant at 1 percent level.

Table 2.--Four year average cone production (per tree) of western white pine by fork rank and age group

Fork rank[1]	Cone production by age group: 15 to 18 years	24 to 29 years
0	15.4	96.1
1	9.4	101.3
2	14.0	95.2
3	10.6	133.6
4	18.6	105.4
5	6.0	138.5
6	25.4	154.9

[1]0 = no forks; 1 = forked at the ground; 2 = forked at 5 feet (1.5 m); 3 = forked at 10 feet (3 m); 4 = forked at 15 feet (4.6 m); 5 = forked at 20 feet (6.1 m); and 6 = forked at 30 feet (9.1 m).

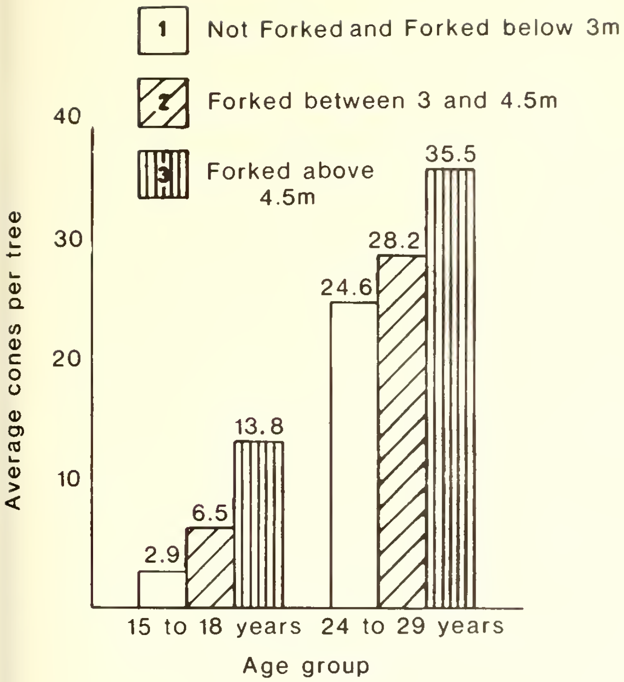

Figure 5.--Expected annual cone production of white pine based on regression of average cones on tree age group and fork class.

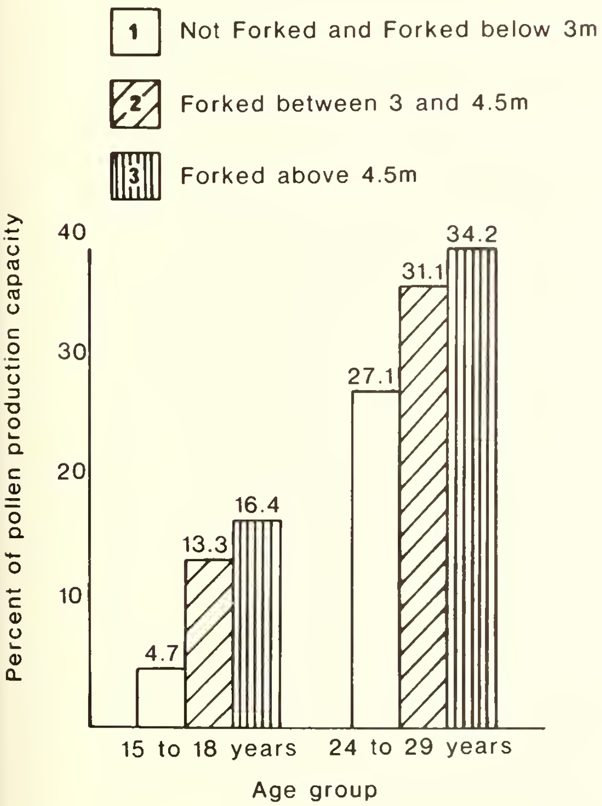

Figure 6.--Expected pollen production based on regression of pollen on tree age and fork class.

increase was 44 percent more than the average value for trees in the not forked class. The predicted values in figure 5 represent the average number of cones per tree per year. Based on the 4-year cone count, trees in the group ranked no forks or forked below 10 feet (3 m) and in age class 15 to 18 may be expected to produce 2.90 cones per year.

Pollen increase was significant at the 95 percent level for trees forked above 15 feet (4.6 m) (fig. 6). A standard t-test was made for all classes and another analysis was made grouping fork height classes 3 and 4 together and classes 5 and 6 together. Both of these grouped classes showed significantly greater pollen production than no forks in the tree (fig. 6). Forking in the lower bole of the tree produced no significant results.

In contrast to what has been reported for many pines, stem pruning in western white pine, 10 feet (3 m) and above from the ground, did increase cone and pollen production in this orchard. The crown form observed in this orchard is the result of unplanned pruning, that is, pruning by climbers and birds. We intend to follow these results with a controlled pruning study.

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

The improvement program of western white pine in the Northern Rocky Mountain region began with research into breeding for blister rust resistance. The cumulative research work of over 30 years, as well as the large monetary expenditures involved, represents a commitment to the perpetuation and improvement of western white pine.

Although more intensive controlled research is needed, several guidelines for the implementation of pruning can be given.

1. Trees should be sexually mature before pruning is initiated. In this study, cone production from 15- to 18-year-old trees showed better response to unplanned pruning than did older, 24- to 29-year-old trees. Pruning on smaller nonflowering trees may increase the time to reach sexual maturity.

2. Pruning should be limited to the upper crown and should involve removal of the previous year's leader growth. More severe pruning would result in the removal of a significant portion of the next year's cone crop. If possible, top pruning should be applied during a year when a minor crop of conelets is evident on the apical leader. A normal bumper cone crop periodicity in western white pine is 4 years. The year following a bumper crop few cones are produced.

3. The frequency of treatment application is dependent upon the desired size of orchard trees, the growth rate and the cost involved with pruning. A significant factor in total cone production is the height of the tree.

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Identifying Sheep Killed by Bears

David E. Griffel and
Joseph V. Basile[1]

BSTRACT

Sheep carcasses located on four allotments over a 3-year ›riod were examined for cause of death, and predator-flicted damage to sheep was noted. Carrion feeding was stinguishable from predation. Bear kills were readily ›parated from coyote kills, but the kill techniques of black ›ars and grizzly bears were too similar to distinguish ›tween them from carcasses alone; other signs at the kill ›e provided the best clue to the responsible bear species. ›edators were responsible for 89 percent of the losses, or 8 percent of the sheep grazed. Black bears killed over ree times more sheep than grizzly bears killed.

EYWORDS: predation, sheep, black bear, grizzly bear, *Ursus americanus, Ursus arctos horribilis*

Bear/domestic sheep relationships were monitored on e Targhee National Forest in southeastern Idaho for three ›azing seasons. The objectives were to verify and quantify ›eep losses on four allotments that have a history of black ›ar (*Ursus americanus*) and grizzly bear (*Ursus arctos* ›rribilis) occurrence, and to determine, where possible, e predator species responsible for the losses. This paper ›esents criteria for identifying sheep killed by black bears ıd grizzly bears.

›ethods

Sheep bedgrounds and their surroundings and trails to e bedgrounds were searched for sheep carcasses four to five times per week during the allotment periods. Each loss was categorized as to cause: black bear, grizzly bear, coyote (*Canis latrans*), or nonpredator related cause, such as disease, poisonous plant, accident, and old age.

The physical damage sustained by a sheep during an initial attack furnished the primary evidence of cause of death. Although bear kills were easily separated from other causes of mortality, differentiating between black bear kills and grizzly bear kills proved difficult because kill techniques are similar. Tracks at the kill sites provided the best clue to the bear species responsible. Carrion feeding was distinquished from predation by the lack of subcutaneous hemorrhage around puncture wounds, an indication that the animal was dead when first bitten or clawed (Davenport and others 1973).

Results and Discussion

Of 19,225 sheep that grazed the allotments over 3 years, 614 (3.2 percent) failed to return. Of 415 carcasses, 370 bore evidence of death by predator and 45, of death from other causes (table 1). The remaining 199 lost sheep were not located. Presumably, their fate paralleled that of dead sheep that were located. If so, approximately 89 percent or 177 were lost to predators.

[1]The authors are, respectively, Wildlife Biologist, Bridger-Teton National Forest, Jackson, Wyo., and Range Scientist, located at the Intermountain Station's Forestry Sciences Laboratory, Bozeman, Mont.

Kill Incidence

Bears killed 332 sheep of which 56 percent were lambs and 44 percent were ewes (table 1). Eighteen black bears were believed to be responsible for 252 sheep deaths and eight grizzly bears for 80. The numbers of sheep killed in each of 151 attack incidents ranged from 1 to 6 and averaged 2.2 Sixteen sheep (nine lambs and seven ewes) survived bear-inflicted injuries in seven incidents. Sheep deaths occurred in three of those incidents. During the 3 years, coyotes killed 35 lambs and three ewes in 21 incidents. Kills ranged from 1 to 4 sheep per incident and averaged 1.8.

Nature of Wounds

Typically, sheep killed by bear had two or more puncture wounds in the nape and/or skull, accompanied by subcutaneous hemorrhaging. Hemorrhaging was noticeable as bloodshot areas just under the skin immediately surrounding the punctures. These puncture wounds, produced by the bear's canine teeth, were found on the napes of 240 carcasses and in the frontal or jugal bones of the skulls of 109 carcasses.

Our findings are similar to those reported elsewhere. Davenport (1953) reported that black bears killed livestock by biting through the nape or through the spine just behind the shoulders. Mysterud (1975) found the most conspicuous wounds on domestic sheep killed by brown bears in Norway were canine tooth punctures of the forehead and nasal region. In Wyoming, Murie (1948) determined that a bite on the dorsal side of the neck or occasionally in the lumbar region of the spine was the wound generally found on cattle killed by grizzly bears.

Each of these workers concluded that deaths in their respective studies were caused by bite wounds. The nasal and facial regions of sheep, which contain several major nerve branches from four different cranial nerves, are particularly sensitive to injury. Mysterud (1975) hypothesized that a deep and sudden bite to either region induces shock and paralysis that results in unconsciousness and hypoxic asphyxiation. In this respect, the biting and killing method of the bears in his study differed from the method commonly associated with mammalian predators, which involves either suffocation through throat bite or brain and spinal cord damage.

Murie (1948) speculated that bites in the lumbar region temporarily paralyzed cattle, but he did not claim death as a consequence. About one-half of the victims had lumbar bites; but these, with one exception, accompanied neck bites. All but one victim had neck bites. Repeated reference to severed vertebrae suggests spinal cord damage as the major cause of death.

In our study, about 20 percent of the bear-killed sheep carcasses showed evidence of facial bites only and therefore, if Mysterud's hypothesis is correct, suggest death by asphyxiation. Another 10 percent of the carcasses showed both facial and nape bites and the remaining 70 percent bore evidence of nape bites only.

Method of Attack

Both Mysterud (1975) and Murie (1948) discount a crushing blow with the forepaw--the reputed kill technique of both the grizzly and the brown bear (Elgmork 1978)--as the cause of death. Murie (1948) insists that the grizzly does not attack by striking with the paws, but instead seizes and holds a victim with its "arms" so as to administer the killing bite. If an animal seized by a bear manages to pull away, it is likely to be clawed. Cole (1972) reported that the grizzly bear attacks elk by rearing on its hind legs and grasping the elk on or over the rump and then letting its weight pull the victim down. To kill, the bear first grabs the elk's neck and shakes the animal vigorously, then it rolls the elk on its back, and opens its abdomen.

Jorgensen (1979) reported the attack/kill methods of bears on sheep as described by several observers on the Targhee National Forest. One sheepman described kills that appeared to have been caused by bears straddling and clawing the backs of sheep; another sheepman ascribed kills to neck bites. A predator control agent blamed clawing and "batting" for the kills he had observed; another agent reported that he has seen more sheep that had been killed by powerful blows than he has seen sheep killed by neck bites. He claimed that the blows failed to break the skin but that subcutaneous hemorrhaging, often accompanied by a broken neck, was characteristic.

Although we have never witnessed a bear attacking sheep, we suspect the usual mode of attack in our study area has been a grasping action rather than a striking blow. A blow sufficiently powerful to kill an animal most likely would have left the telltale marks mentioned above--broken neck, and a subcutaneous hemorrhage under unbroken skin at the site of the blow. We have found no evidence of this. Instead, all subcutaneous hemorrhages were associated with bite wounds, and every bear-killed carcass bore

Table 1.--Sheep losses to predators as determined from 415 carcasses on four allotments on the Targhee National Forest, Idaho, 1976-1978

Cause of death	Sheep killed	Kill composition: Lambs	Kill composition: Ewes	Sheep killed/attack: 1	2	3	4	5	6	Sum
		- -Number (percent)- -		- - -Number (percent) of attacks- - -						
Black bear	252	145(58)	107(42)	49(42)	34(29)	19(16)	4(3)	4(3)	7(6)	117
Grizzly bear	80	42(52)	38(48)	9(26)	12(35)	7(21)	4(12)	2(6)	-	34
Coyote	38	35(92)	3(8)	10(48)	7(33)	2(10)	2(10)	-	-	21
Subtotal	370	222(60)	148(40)							
Nonpredator	45									
TOTAL	415									

claw-inflicted lacerations over the cervical, thoracic, or lumbar regions. The 16 sheep that escaped bear attacks with nonfatal injuries were similarly lacerated. We speculate that these lacerations resulted from the sheep trying to escape a bear's grasp.

We cannot discount the possibility that some lacerations resulted from glancing blows or swats not sufficiently well placed to kill the sheep, but powerful enough to slow or stop it and allow the bear to administer the killing bite.

In an incident outside our study allotments, two subadult grizzlies killed 30 sheep in one evening. An undetermined number of these apparently were struck while running; as the sheep fell and were rolled over, the bears ripped open their abdomens and their viscera became extended. This incident supports Spencer's (1955) suggestion, reported by Jorgensen (1979), that the bite attack is more common in one-on-one encounters and forepaw blows are characteristic of mass killings.

Sheep killed by coyotes were distinguishable from those killed by bear because coyotes usually bite sheep on the underside of the neck just behind or below the ear (Connolly and others 1976; Bowns 1976). Oftentimes the victim's throat is ripped out. All 38 coyote-killed sheep had throat damage.

Carcass Dragging

Bears dragged 60 percent of the carcasses approximately 75 to 150 ft. (23 to 46 m) from the kill sites and the rest less than 65 ft. (20 m). Coyotes seldom moved carcasses more than 3 ft. (1 m), particularly in timbered areas.

Carcass Consumption

The 243 carcasses fed upon by bears revealed a pattern of consumption. Point of entry was the udder (74 percent) or the flank (26 percent); on all lactating ewes the udder was consumed first. Carcasses were opened ventrally from the udder forward and the viscera were cleanly removed. The heart and liver were eaten next. If the carcass was fed upon further, the bear removed the hide, usually intact, by splitting it over the rib cage and peeling it off the more fleshy portions of the carcass. The animal ate the articulation of the costal arch and sternum, leaving jagged-ended ribs attached to the vertebrae. The bear next ate the proximal end of the front shoulder, leaving the hind quarters for last.

Coyotes partially consumed 13 (lambs) of the 38 sheep they killed, gaining entry into all but one of these through the flank immediately anterior to the hind leg and through the udder on the one remaining carcass. This agrees with findings by Roy and Dorrance (1976), who reported that entry was typically through the flank. Coyotes tended to eat more of the viscera, fatty, and meaty portions of the carcass and to leave the larger bones, which many times bears consumed. Coyotes seldom removed the hide intact as bears did.

Eighty-nine (27 percent) of the sheep killed by bears were not fed upon, but another 88 (27 percent) were totally consumed within 12 hours of the estimated time of kill. The remaining 155 carcasses (47 percent) were only partially consumed within 12 hours of the kill. The bear usually returned within 18 to 36 hours of the kill to finish eating the carcass.

Coyotes did not return to any of their kills; bears usually ate the coyote kills within 1 1/2 days of the kill.

Eighteen of the 45 nonpredator related losses were examined within an estimated 4 hours of death and bore no sign of predator damage. The other 27 had been partially fed upon by bears. Sheep fed upon by bears as carrion can be distinguished from sheep killed by bears. A lack of canine tooth punctures in the neck, shoulder, or facial regions, of hemorrhaging, and of lacerations over the back indicate that the bear was consuming carrion and did not kill the sheep. Cause of these deaths may be labelled erroneously, yielding a biased estimate of losses to predators.

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Field and Laboratory Methods for Age Determination of Quaking Aspen

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Field and Laboratory Methods for Age Determination of Quaking Aspen

Robert B. Campbell, Jr.[1]

ABSTRACT

The diffuse-porous wood of aspen (Populus tremuloides Michx.) *makes the annual rings difficult to distinguish. The technique described uses nonspecialized equipment to analyze a shaved, translucent core with simultaneous direct and reflected fluorescent lighting to discern rings. Proper field procedures, such as boring the correct side of the tree, recording the core height, and avoiding heart rot, can improve the accuracy of the ages obtained.*

KEYWORDS: *Populus tremuloides,* aspen, age analysis, increment cores, annual rings, diffuse-porous wood, fluorescent lighting

The diffuse-porous wood of quaking aspen (*Populus tremuloides* Michx.) makes age determination difficult. This paper describes procedures for collecting aspen increment cores and distinguishing annual rings. The number of different methods discussed in the literature is indicative of the problems encountered in aging aspen.

Glock (1937) discussed tree-ring analysis of conifers, and many of his concepts apply to aspen. He preferred using blocks and discs to increment cores. His basic ideas included using transverse sections, preparing a smooth surface with razor cuts, using direct and reflected light, and wetting specimens with kerosene.

Aspen cores have been pretreated by soaking them in water (Maini and Coupland 1964; Brace 1966; Jones 1967; Svoboda and Gullion 1972), hot black coffee (Archibold and Wilson 1978), or water and alcohol (Marts 1950). Ghent (1952, 1954) impregnated specimens with hot wax, while Rose (1957), Maini and Coupland (1964), and Jones (1967) saturated cores with light oil. Patterson (1959) used phloroglucinol and hydrochloric acid to stain the lignin red, causing a contrast among rings. Jones (1967) experimented with benzidene, kerosene, and saliva, and also rubbed the core lightly with a soft lead pencil.

Transmitted light aids tree-ring analysis (Ghent 1952, 1954; Rose 1957; Maini and Coupland 1964; Svoboda and Gullion 1972). Fluorescent light was deemed a significant benefit in distinguishing rings (Marts 1950; Patterson 1959). Trujillo (1975) shaved fresh cores prior to drying and then treated the cut surface with pentachlorophenol in kerosene. The cores were redried, stored, and later examined without further treatment. Transverse sections cut with a razor blade or sharp knife accentuated the rings (Glock 1937; Marts 1950; Jones 1967; Trujillo 1975). Ghent (1952, 1954), Rose (1957), and Maini and Coupland (1964) preferred using thin sections of their specimens. Most of these researchers viewed the specimens through either dissecting or regular microscopes. Maini and Coupland (1964) stressed that laboratory analysis was essential for accuracy.

Many of these techniques are similar. Some are complicated and many work best only in specific cases (for example, on young trees or light colored wood). My technique, primarily a combination of those of Glock (1937) and Maini and Coupland (1964), is simple, requires little specialized equipment, and in most cases yields satisfactory results.

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THE FIELD TECHNIQUE

Certainly the most accurate proçedure for determining a tree's age would use an entire cross section of the bole (Glock 1937; Ghent 1952, 1954), but cross sections are seldom practical to obtain. Therefore, an increment borer is used to remove a core from the tree. Each borer has three parts: the handle, the bit, and the extractor. Bits vary in length and inside diameter. I prefer the larger inside diameter of 0.216 inch (5.49 mm) with aspen cores to reduce warping and breakage after drying. In a thorough discussion of increment cores and borers, Maeglin (1979) emphasizes that the bit must be kept clean and sharp for good results. In addition, he cautions that trees sampled with increment borers usually develop disease. Laflamme (1979) showed that core wounds in aspen may not heal at all or at least slower than in most other tree species. These unhealed wounds become infection sites for bacteria and fungi and result in disease and stained wood.

A tree must be bored correctly before an accurate count of its annual rings is possible. The three main sources of error in determining a tree's age are (1) rings that are too narrow to distinguish, (2) estimating the number of rings to the tree's center if the pith is not present in the core, and (3) estimating how many years the tree grew before reaching the core height. In this paper, I will explain the basic field procedure, and then discuss field techniques that reduce error in these three categories.

Recommended Boring Procedure

Select a tree with a uniform bole lacking any obvious sign of stem rot. Generally, the best place to bore the tree is 1 foot above the ground and on the concave side of any butt sweep.

After assembling the borer, press the bit's threaded cutting edge firmly against the bole, aim toward the tree's central axis, and rotate the handle clockwise. Continue turning the borer until the cutting edge penetrates to about 75 percent of the tree's diameter. Completely insert the extractor inside the bit on the core's lower side and press firmly to seat the extractor's serrated tip into the core. This binds the core to the bit. Now turn the handle one full turn counterclockwise to break the core loose at the cutting edge. With the bit still in the tree, remove the extractor and the core. While the serrated tip firmly holds the core's pith end on the extractor tray, gently slide a plastic drinking straw over the core, bark end first. The bark end is not attached to the tray; thus, the straw slides between the core and inner surface of the tray until the entire core is enclosed in the straw.

Tension Wood and Wide Rings

Careful selection of the boring location based on knowledge of the development of reaction wood reduces time in the field and improves the accuracy of the final data. Most angiosperms, including aspen, develop tension wood when growing in leaning positions (Kozlowski 1971). The formation of tension wood on the upper side of the leaning stem results in eccentric growth (fig. 1). Thus, the rings on the upper side of the leaning tree are much wider than those on the lower side, and the pith is not at the geometric axis of the bole. This condition is often

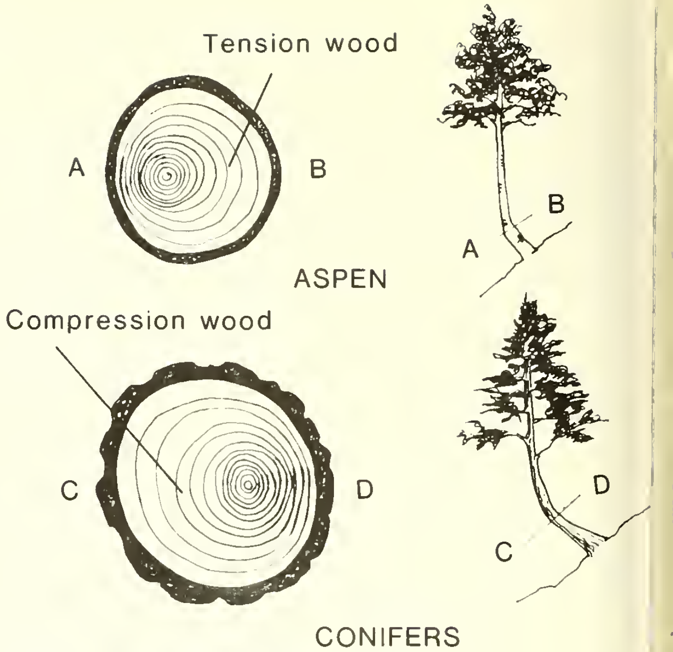

Figure 1.--Two types of reaction wood. Modified from Fritts (1976).

characteristic of aspen growing on sloping terrain. Ir contrast, conifers exhibit a geotropic phenomenor known as compression wood that results in wide eccentric rings on the lower side of the lean (Kozlowsk 1971).

Therefore, boring aspen from the upper side of the lear and perpendicular to the bole's geometric axis reduce error in determining the tree's correct age. Generally such a core will contain the radius with the widest most discernable rings and the tree's true center. Thi radius may even comprise 75 percent of the total diametei Cores from the downhill side usually have narrower an sometimes ill-defined rings.

In addition to age calculations, increment cores ar frequently used to ascertain growth rates by measurin the widths of annual rings. Because of the eccentri nature of the annual rings in the reaction wood of leanin aspen, the ring width measurements along a single radiu may not be suitable for determining growth rates. If leanin aspen must be sampled to estimate growth rates, the core should be removed from the tree's lateral side, not th uphill or downhill sides.

The Importance of the Pith

When the core is removed from the tree, the pith may no be present and the number of missed rings must b estimated. To obtain more accurate data, remove a secon core from the tree. While the first core is in the extracto tray, the orientation of the partial rings indicates whethe to bore to the right or the left of the first hole. Estimat how far to either side by the size of the ring arcs near th tree's center (smaller arcs are closer to the pith). Reborin the tree is time consuming and cannot be done consistentl if field time is limited. Nevertheless, if a core contain the pith, one source of error is eliminated.

ore Height and Heart Rot

Foresters generally core trees at breast height, 4.5 ft .37 m), but often it is necessary to bore aspen at 1 to 2 ft).3 to 0.6 m) or occasionally up to 6 or 7 ft (1.8 to 2.1 m) to /oid heart rot. Since an aspen usually grows for several ɜars before reaching breast height, an estimate must be ade of the number of years required to reach the core ɜight and added to the total number of rings counted. I ɜe an arbitrary estimate (table 1), but realize that great ıriation occurs naturally among clones and sites. Aspen ıckers can reach breast height in 1 year, but 2 to 5 years more characteristic (Jones 1967). If decay is not present, ;curacy should increase when cores are taken from a wer and uniform height. Always record the core height each specimen.

able 1.--An estimate of the age of an aspen sapling at given core heights

Core height	Number of years to reach the core height
Feet	
0.0 - 2.0	1
2.1 - 3.0	2
3.1 - 4.0	3
4.1 - 4.5	4
4.6 - 5.0	5
5.1 - 5.5	6
5.6 - 6.0	7
6.1 - 6.5	8
6.6 - 7.0	9

Heart rot is a major problem for aging aspen. While ınual rings in a core discolored by early stages of decay e difficult to distinguish, they still can be counted. ɔwever, entire, undisturbed cores can seldom be moved from trees with medium to advanced stages of ɜart rot. To prevent frustration and wasted time in e laboratory, discard all rotten cores and bore another ɜe. Occasionally, it may not be possible in an overmature one to find a tree without heart rot. If not, bore the ɜe at several heights on the stem; this may yield a core th minimal decay.

oring the Core

Increment cores are fragile and require careful handling ıd storage. I suggest inserting the core in a plastic inking straw of 0.25 by 8.25 inches (0.64 by 20.96 cm) ter Cole (1977); however, I seal both ends with corks ize 000). Identify the core by writing on tape that has been apped around the straw. Aspen cores frequently break ıt can be repositioned end to end like a puzzle if the ɜces of more than one core are not mixed. To commodate longer cores, break the core and insert the ɜces in separate straws. Cole (1977) presents the llowing three suggestions. Seal each end of the straw th cellulose-acetate tape that can be labeled with pen or ncil. Store longer cores in two straws that are joined slightly flaring the end of one straw, inserting the end of ɘ other straw, and taping the joint. For extended storage, ɜeze the cores to reduce shrinkage and fungal growth in ɘ specimen.

THE LABORATORY TECHNIQUE

Several simple steps can be used in the laboratory to clarify the annual rings. Attention should be given to core preparation, lighting, and interpretation of the annual rings. The equipment and supplies needed are:

--machinist vise with jaws 4 to 6 inches (10.2 to 15.2 cm) long
--razor blades and holder (the entire cutting edge should be exposed and parallel to the handle)
--test tubes, stoppers, and rack
--wetting solution
--metal rod with diameter $<$ 0.25 inch (0.64 cm)
--dissecting scope
--clear scope stage or elevated glass plate
--fluorescent light above and below the stage
--red-leaded pencil
--curved dissecting needle

Core Preparation

Fresh cores usually contain enough sap to be translucent; however, dry cores need to be soaked in a wetting solution. A wetting solution can be prepared by combining water, methyl alcohol (MeOH), and laboratory detergent, 75:24:1 by weight. Use a small metal rod to push the cores from the plastic straws. Place each core in a test tube filled with wetting solution and soak for 24 to 48 hours. A vacuum system significantly reduces the amount of time needed to completely permeate the core (Marts 1950; Rose 1957; Maini and Coupland 1964). Cores become translucent when saturated, yielding clarity in distinguishing annual rings.

Next, clamp the core horizontally in the vise, vessel elements perpendicular to the cut, so that one quarter of the core extends above the vise's jaws. A narrow platform of wood or cardboard placed in the vise beneath the core aids in positioning the core (fig. 2). Use a razor blade to remove the upper quarter of the core, exposing a distinct, transverse view of the rings. Wet cores are easier to shave, especially if thin, ribbonlike strips are desired. Change the razor blades often for best results (Glock 1937; Trujillo, 1975). The exposed surface must be a cross section, not a radial view of the vessel elements.

Lighting and Ring Counts

Examine the core's shaved surface through a dissecting scope and use simultaneous fluorescent light from above and below. If the dissecting scope does not have a transparent stage and substage fluorescent lighting, improvise a stage by placing a fluorescent light beneath an elevated glass plate. I prefer the 7X to 10X magnification range. Glock (1937) suggested starting at the pith and counting from the left to right toward the bark. He put a pin hole (use a curved dissecting needle) on every 10th ring, thus allowing a double check for increased accuracy. Also, a red-leaded pencil is useful in marking every 10th ring. The cut surface dries rapidly; some rings may become more distinct during the process. A few drops of wetting solution will rewet the entire core immediately. Svoboda and Gullion (1972) stressed rotating the core to orient the vessel elements and fibers parallel to the light rays for best

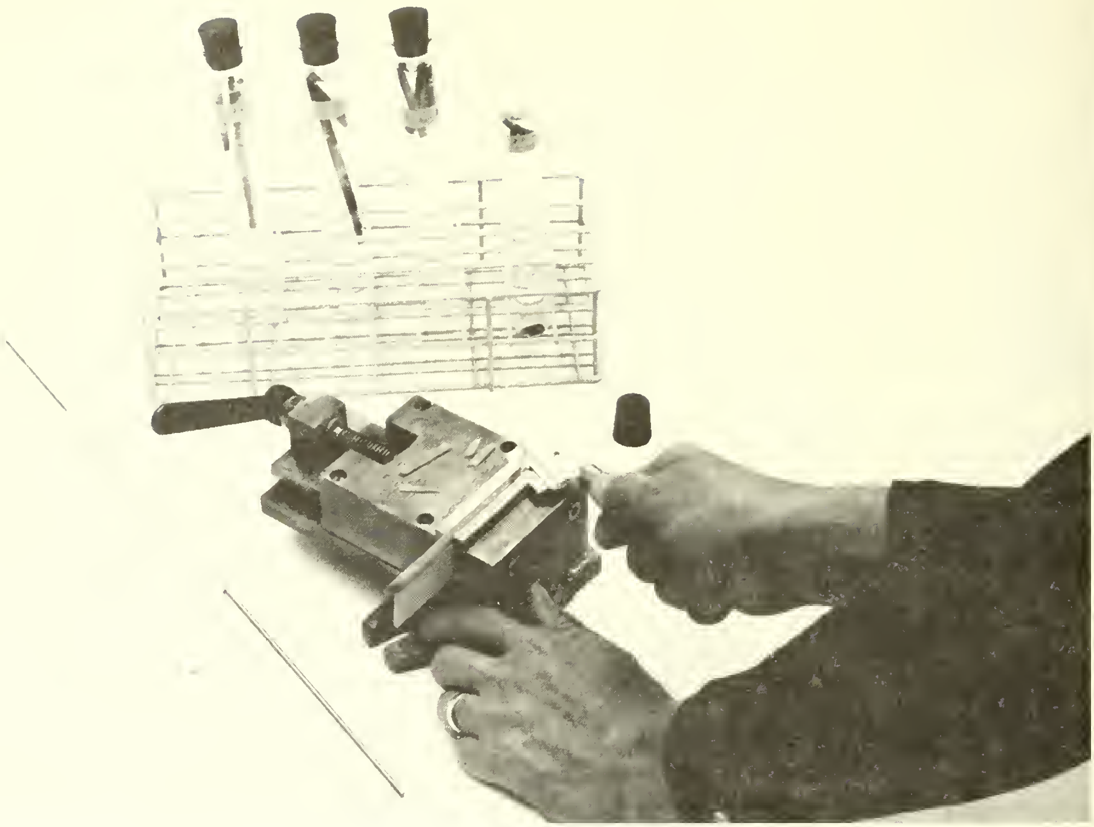

Figure 2.--Shaving an increment core that is clamped in a machinist vise. Note the related equipment.

illumination. I often roll the core about 60° in either direction until I obtain maximum contrast among rings.

Core Interpretation

Figure 3 depicts two cores removed from the same tree. Unlike core B, core A does not contain the tree's center. To estimate the number of rings to the center, I use a modification of Applequist (1958). Prepare an arbitrary standard on a card by drawing a series of 10 concentric circles (or half circles) representing the dimensions of a cross section from a 10-year-old aspen sapling. Position the core over the standard to obtain the best fit. Then, count the number of rings to the center on the standard. The error factor may be large when more than 10 years at the center are missing. Ring widths may vary tenfold at different stages of the tree's growth. Therefore, ring estimations for missing pieces are also unreliable. In either case, a more complete core should be obtained. If the core is replaced in the straw for later reference, do not seal the straw until the core dries completely.

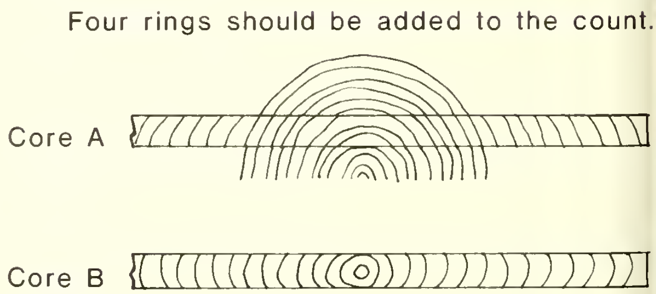

Figure 3.--Estimating the number of rings to the tree's center.

Finally, the tree's total age is the sum of: the annual rings actually counted, the estimated number of years to reach the core height, and if the pith is missing, the estimated number of missing rings.

Heart rot makes age determination difficult because the dark wood does not become translucent after wetting. However, one additional step may be helpful for cores with initial stages of decay. After the top one-quarter of the core has been shaved and removed, reposition the core in the vise and carefully shave a ribbon-like strip the full length of the core. The thin specimen is quite translucent but extremely fragile. Although the rings will be more distinct, they will be difficult to discern because of a lack of contrast in specimen color.

False rings or double rings may occur in climates with limited rainfall divided between two rainy seasons. Such a weather pattern often results in two distinct periods of growth separated by a period of dormancy (Glock 1937). This climatic condition is seldom found in the aspen zones of the Rocky Mountains.

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Cone Production of Western White Pine Seedlings and Grafts

R. J. Hoff[1]

ABSTRACT

Grafts of western white pine planted in a seed orchard within the white pine type produced 6 cones per tree 11 years after grafting; grafts of the same families in a breeding arboretum located on a grassland habitat produced 1.6 cones per tree 14 years after grafting. Seedlings in the breeding arboretum produced 1.2 cones per tree at 12 years of age. Placement of seed orchards of western white pine is discussed.

KEYWORDS: cone production, seed orchards, western white pine.

The final efforts of tree improvement is to produce seed of improved varieties. Most forest tree species will produce more seed sooner on particular sites (Falconer 1975), and grafts usually produce before seedlings.

After choosing a species to improve, tree breeders should immediately begin to plan seed orchard locations and to decide whether to vegetatively propagate parent trees or to use seedlings. Failure to do so may mean delays in seed production.

Records of cone production of western white pine in the inland portion of its range have been gathered for many years, and some data have been published (Bingham and Squillace 1957; Barnes and others 1962; Barnes and Bingham 1963; Barnes 1969; Bingham and Rehfeldt 1970; Rehfeldt and others 1971; Bordelon 1978; Hoff[2]). This note summarizes data on cone production for grafts of mature trees growing at two locations and for seedlings at one location.

[1]Principal plant geneticist located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

[2]Hoff, R. J. 1978. Mountain pine cone beetle damage in the Sandpoint Seed Orchard. *In* Progress Report, Inland Empire Cooperative Forest Tree Improvement Program. p. 37-40. Intermt. For. and Range Exp. Stn., Moscow, Idaho.

MATERIALS AND METHODS

Cone production data were collected from western white pine growing at two different sites in northern Idaho. One site is located near Moscow, Idaho, and is called the Moscow Arboretum. The second site is near Sandpoint, Idaho, and is called the Sandpoint Seed Orchard.

The Moscow Arboretum site is part of the Palouse prairie, an *Agropyron spicatum:Festuca idahoensis* habitat type. The average frost-free period is 123 days and average annual precipitation is 508 mm (20 inches). The arboretum was irrigated from 1958 to 1968. The seed orchard at Sandpoint is located within a typical white pine site, a *Tsuga heterophylla:Pachistima myrisinites* habitat type. Its average frost-free period is 121 days and average precipitation is 762 mm (30 inches).

Moscow Arboretum contains grafts of phenotypically resistant western white pine from native stands and seedlings of two parent crosses of phenotypically resistant trees. The 44 grafts are from 22 clones with 1 to 4 ramets per clone. Seedlings come from 509 families with 1 to 20 individuals per family and total 1,356.

The grafts were made in a greenhouse in 1951-52 and grown in a lathhouse until planted in the arboretum in 1958. The seedlings were survivors from several progeny tests for selecting white pine seedlings resistant to blister rust. Although the progeny tests spanned several years, they were planted into the arboretum in two basic groups. Therefore, this paper will treat the seedlings as the "old trees" (seedlings from the 1952, 1953, 1954, and 1955 progeny tests) and the "young trees" (seedlings from the 1961, 1962, and 1963 progeny tests).

Seedlings of the 1952-55 progeny test were sown in 5-cm x 5-cm x 20-cm (2-inch by 2-inch by 8-inch) containers in a nursery near Spokane, Wash. The seedlings were artificially inoculated with white pine blister rust in September following their second growth period. They were then outplanted into a natural forest area where they received natural exposure to blister rust. The most resistant seedlings from each family were lifted and planted into the arboretum from 1958 to 1961.

Seed of the 1961-63 progeny test was sown in nursery beds at Moscow, Idaho. Seedlings were inoculated artificially with blister rust in September after their first growing period. The most resistant seedlings were lifted and planted in the arboretum from 1964 to 1967.

The Sandpoint Seed Orchard was established in 1960 using grafts of 13 phenotypically blister rust resistant trees in native stands. The grafts were made in a greenhouse in 1959. In 1960, there were over 100 ramets per clone. Between 1964 and 1967 one of the less resistant clones was replaced by a clone with higher resistance and four clones from high elevations were replaced by clones from low elevations. Also, incompatibility of four clones appeared in 1970; this destroyed about 75 percent of the ramets of each of four clones. By the fall of 1980 there were 811 trees left in the orchard. Only 444 original grafts (those made in 1959) remained by the fall of 1980.

For the Moscow Arboretum, cones for each individual seedling were counted from 1960 (first cones produced) through 1969 and from 1976 through 1980. Between 1970 and 1975, only the total number of cones produced was tallied. For the Sandpoint Seed Orchard, the number of cones per graft were counted from 1960 through 1969 and in 1980, and the total number harvested from 1970 to 1979.

Height of all trees in both locations was measured during the winter of 1969-80.

Data are presented as the number of cones per tree. To determine the effect of height and family on cone production in the arboretum, we used the families of the old tree group with at least three individuals per family. Cones were totaled over years. Analyses of variation, correlation, and regression were performed by least squares using the GLM Procedure contained in SAS (1979).

RESULTS AND DISCUSSION

The older tree group in the Moscow Arboretum started producing cones when they were 8 years old (table 1), but no substantial production occurred until 22 years. They were at least 24 years old (after sowing) before a "breeding population" developed (with at least 50 percent of trees producing cones and pollen). The arboretum grafts produced first cones 13 years after grafting, but did not develop a breeding population until 26 years.

The grafts at the Sandpoint Seed Orchard produced cones the first year after grafting and a breeding population developed 11 years after grafting (table 1). Actual harvest at Sandpoint for 1977 and 1978 does not reflect the cone production potential because nearly 90 percent of the cones during those two rather large cone years were lost due to insect damage.

Table 1.--Cone production of western white pine in Moscow Arboretum and Sandpoint Seed Orchard

	Moscow Arboretum				Sandpoint Seed Orchard (grafts)	
Cone year	All trees[1]	Young trees[2]	Old trees[3]	Grafts[4]	Trees[5]	Cones/tree
	Cones/tree					
1960	0.01		0.02	0	1,426	0
1961	.01		.02	0	1,054	0.003
1962	.09	0	.02	0	933	.004
1963	.01	0	.02	0	954	.01
1964	1.2	0	2.0	1.6	920	.9
1965	1.9	0	3.0	2.0	982	.1
1966	.5	0	.9	1.3	945	.2
1967	.4	0	.6	.4	1,016	.1
1968	.4	0	.5	1.4	1,200	.6
1969	3.6	0	6.1	.2	1,300	.6
1970	2.0				1,364	6.2
1971	3.9	Data not compiled by individuals for these years			1,340	3.7
1972	.2				1,331	2.3
1973	1.4				1,331	6.0
1974	6.5				1,109	20.6
1975	7.0				954	5.2
1976	14.0	0.9	20.5	14.4	880	6.5
1977	22.4	2.3	34.5	32.7	863	2.3
1978	32.0	4.3	49.0	38.0	863	5.0
1979	2.2	1.7	2.6	1.3	811	0
1980	21.1	4.1	31.4	37.4	795	80.3

[1]These data reflect cone production for the 1,365 individuals of western white pine in the arboretum.

[2]Includes trees from the 1961, 1962, 1963, and 1964 sowings - 510 individuals.

[3]Includes trees from the 1952, 1953, 1954, and 1955 sowings - 811 individuals.

[4]Grafts of various candidate trees made in 1950 and 1952 - 43 individuals.

[5]Grafts made mainly in 1959, but some were made between 1964 and 1968.

In 1979, the average height of the older arboretum trees was 7.3 m (24 ft); the height of the grafts in the arboretum averaged 7 m (23 ft). The average height of the Sandpoint Seed Orchard grafts (made in 1959) was 9.5 m (31 ft). Table 2 compares grafts of the same clones at Moscow and at Sandpoint. Obviously, white pine grows much better at Sandpoint.

Nearly 50 percent of the variation in total cone production within the older tree group in the arboretum was due to height and family (R^2 = 0.49). For Sandpoint Seed Orchard the R^2 was 0.34. Both variables were significant (table 3). Family means adjusted for height for the arboretum varied from 31 to 239 cones per tree with a mean of 132; families in Sandpoint Seed Orchard varied from 50 to 200 with a mean of 107. The regression coefficient for height on total cones was 30.3 cones per meter (9.4 cones per foot) for the arboretum and 14.1 cones per meter (4.3 cones per foot) for Sandpoint Seed Orchard.

The Moscow Arboretum was not intended to be a seed orchard. However, the fact that the trees in the arboretum did produce cones provided the opportunity to compare it to a site that was specifically chosen as a seed orchard--the Sandpoint Seed Orchard. Although this may not be a valid comparison, it does indicate some of the limiting factors that come into play in seed production of western white pine.

The Sandpoint Seed Orchard site is obviously the better site. The trees not only produced sooner at a fairly high level but were also more vigorous, faster growing trees. The almost complete loss of 1977 and 1978 cone crops to cone insects at Sandpoint, when compared to very small losses in the Moscow Arboretum, somewhat offset these advantages. The arboretum is 8 to 9 miles from the nearest natural white pine stand; therefore, fewer insects get to the arboretum. Sanitation methods were probably more effective, also.

Several limiting factors stand out when the two sites are compared (table 4). The only similarity between the two sites was the number of frost-free days. Even here there is a timing difference. Spring is later at Sandpoint, but the frost-free period extends longer into fall. After observing the two sites over the last 20 years, I feel that one of the most important environmental factors is the difference in winter exposure. The arboretum trees suffer much wind damage, not only from breakage but also from drought stress.

Concerning the insect damage at Sandpoint, the production history of western white pine indicates that insects will pose no real problem because the species produces frequent abundant crops (Barnes and others 1962; Bingham and Rehfeldt 1970; Rehfeldt and others 1971). And in the decade from 1971 to 1980 there were only 3 years (1972, 1973, and 1974) when few cones were produced in mature stands.

The data presented in this paper seem to indicate that the best site for a white pine seed orchard is within the white pine type. It seems reasonable to expect, however, that the species will perform in a longer growing period if some of the environmental factors critical to white pine growth and production are provided or ameliorated--especially soil moisture, pH, and wind protection. Other factors not addressed in this paper that are probably important are humidity and/or air temperature. Rehfeldt (1979) showed that white pine grew much better in a site with lower temperatures and higher humidity. These requirements would not be difficult to provide with an irrigation system set up to mist the orchard at certain temperature or humidity levels.

Table 2.--Comparison of height and diameter of grafts of the Moscow Arboretum and the Sandpoint Seed Orchard

	Sandpoint			Moscow		
Family	Ramets	Height	Diameter	Ramets	Height	Diameter
		m (ft)	*cm (in)*		*m (ft)*	*cm (in)*
17	89	10.4 (34)	18 (7)	2	7.0 (23)	13 (5)
19	49	8.8 (29)	15 (6)	1	3.7 (12)	8 (3)
22	88	9.5 (31)	15 (6)	3	7.0 (23)	15 (6)
24	63	9.5 (31)	15 (6)	1	4.6 (15)	13 (5)
37	33	9.5 (31)	15 (6)	1	8.5 (28)	20 (8)
58	38	10.7 (35)	15 (6)	2	7.6 (25)	13 (5)

Table 3.--Analyses of variance by least squares for the effect of height and family on cone production in Moscow Arboretum and Sandpoint Seed Orchard

	Moscow Arboretum[1]		Sandpoint Seed Orchard[2]	
Source	MS	F value	MS	F value
Family	22,749	3.14**	10,310	7.35**
Height	1,785,765	246.42**	191,843	136.77**
Error	7,247		1,403	

**Significance of value at 0.01 level of probability.
[1]Performed only for the older trees, 649 trees.
[2]Performed on the grafts made in 1959, 444 trees.

Table 4.--Factors that may reveal causes for differences of cone production between the Moscow Arboretum and the Sandpoint Seed Orchard

Factors	Moscow Arboretum	Sandpoint Seed Orchard
Frost-free period	May 12-Sept. 6 (123 days)	May 18-Sept. 16 (121 days)
Precipitation	508 mm (20 in)[1]	762 mm (30 in)
Winter exposure	Open site with much wind damage	Protected, with little or no wind damage
Soil type	Palouse loess	Mission loam
Soil acidity	pH 7.8	pH 5.9-6.5
Ecological site	Natural grassland	Typical white pine type

[1]The Arboretum was irrigated with sewage effluent from 1958 to 1968 and again in 1977 following the winter drought of 1976-77.

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Research Note
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Rooting Purple Sage Stem Cuttings

Richard L. Everett and Clayton R. Gautier[1]

ABSTRACT

Rooting of semihardwood cuttings of purple sage (Salvia dorrii) *with and without mist, bottom heat, root inducing substance (naphthalene-acetic acid/ indolebutyric acid [NAA/IBA]), and fungicides (dichlone and captan) was evaluated. More than 75 percent of the NAA/IBA-dichlone treated cuttings rooted when placed in unheated rooting benches. Available rooting techniques for purple sage should make commercial propagation possible once quality cutting stock is developed.*

KEYWORDS: misting effects, bottom heat effects, root inducing substance x fungicide interactions, Great Basin shrub, *Salvia*

Purple sage (*Salvia dorrii* [Kell.] Abrams), an attractive drought-tolerant shrub species native to many of the Western States, is potentially useful for roadside revegetation and urban horticulture. The plant is evergreen, low (2.5-13 inches [1-5 dm], and spreading (10-38 inches [4-15 dm] diameter) in form, and sends up a profusion of purple flowers from May through June. Purple sage grows well on disturbed sites and is not eaten by most rodents, a constant threat to transplant survival.

Purple sage has been propagated from seed and stem cuttings; however, seed is not readily available and its germination requirements are uncertain. Up to 6 months are required to raise plants from seed to a sufficient size for transplanting. Semihardwood cuttings, on the other hand, root in approximately 2 months and potted cuttings can be transplanted as soon as root development is adequate. Purple sage has a potential for stem cutting propagation (Everett and others 1978) but improved rooting techniques are needed.

Weiland, Frolich, and Wallace (1971) found that heating the rooting medium increased rooting on cuttings of several Great Basin shrub species. They also found that cuttings of some xeric shrub species rotted under mist conditions. Charles (1962) had trouble with disease when he misted cuttings of desert willow (*Chilopsis linearis* [Cav.] Sweet) and *Vauguelinia californica* (Torr.) Sarg., two southern desert species. Therefore, we decided to examine the effects of mist and bottom heat on purple sage cuttings.

Snyder (1966) reported that interactions from combining root inducing substance (RIS) and fungicide treatments can produce exceptionally high rooting success in some species of plants. Fungicides found to be most effective in combination with RIS were: n-trichloromethylthio-4-cyclohexene, 1,2-dicarboximide (captan); 2,3-dichloro-1,4-napthoquinone (dichlone); tetramethylthiuram disulfide (thiram); and ferric dimethyldithiocarbamate (ferum).[2] Our own pilot studies with fungicides indicated captan and dichlone would improve rooting of purple sage cuttings.

METHODS

Purple sage cuttings were treated with six hormone-fungicide combinations. Two fungicide treatments-captan and dichlone--and no treatment were each tested separately in combination with one of two RIS treatments, a 50-50 (w/w) mix of naphthaleneacetic acid (NAA) and indolebutyric acid (IBA) and none. Fungicide-RIS treatments were tested under four rooting bench environments: misted with and without heat and hand watered with and without bottom heat.

Four large purple sage plants were collected on February 1, 1978, from a stand growing near Virginia City, Nev., and transported to the greenhouse under moist conditions. Semihardwood cuttings (leafy secondary growth) were taken from the terminal stems of the plants. Cuttings 0.13 to 0.51 inch (2 to 5 mm) in diameter and less than 5.1 inches (13 cm) in length were used.

Cuttings treated with RIS had their basal ends dipped in a concentrated solution (4,000 p/m) of combined NAA and IBA as described by Hartmann and Kester (1968). Fungicide-treated cuttings were either dipped in water or the RIS solution before being dusted with the selected fungicide (50 percent active ingredient). Treated cuttings were then placed in steam-pasteurized horticulture-grade perlite on the rooting bench.

[1]The authors are, respectively, range scientist and biological technician located at Intermountain Station's research laboratory, Renewable Resources Center, University of Nevada Reno.

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Half of the rooting bench was supplied moisture by an automatic evaporative demand misting system. The other half was hand watered daily to keep the rooting medium moist. Each half was divided into two sections and bottom heat supplied to one of the two sections by means of heating cables. Rooting bench temperatures were 64° to 73° F (18° to 23° C) for heated sections and 50° to 70° F (10° 21° C) for unheated sections. Air temperature in the greenhouse was maintained at 54° to 70° F (12° to 21° C).

The six RIS-fungicide treatments were replicated four times within each of the four sections of the rooting bench. Each replicate consisted of 12 cuttings. Replicates were located randomly within each section. Each plant provided cuttings for one replicate of the six RIS-fungicide treatments in each quarter of the bench. Therefore, the four plants were equally represented in all treatments and all quarters of the bench. Confounding of treatment effects by genetic differences in rooting ability among the four plants was thus eliminated in this design.

Cuttings were removed from the rooting bench after 10 weeks (February 3 to April 4, 1978). The number of cuttings with roots longer than 0.39 inch (1 cm) were recorded for each replicate.

To make the data more closely fit a normal distribution, numbers of cuttings rooted were transformed $\sqrt{x + 1}$, as suggested by Snedecor and Cochran (1957). Because the four misting-bottom heat combinations were not replicated and no statistical comparison was possible among them, the six RIS-fungicide treatments were analyzed in four separate analysis of variance tests. Hartley's sequential method of testing (Snedecor and Cochran 1957) was used to compare individual means when F values were significant.

RESULTS AND DISCUSSION

Greatest rooting (77 percent) occurred on misted, unheated cuttings treated with dichlone and RIS (table 1). The mean number of rooted cuttings ranged from 4 to 77 percent among the treatments.

Cuttings treated with RIS and dichlone or RIS alone, without bottom heat, rooted significantly more than all other treatments. When bottom heat was applied, in conjunction with either misting or hand watering, there were no significant differences among treatments. Apparently bottom heating increases rooting of cuttings not treated with RIS and reduces rooting in treated cuttings.

The effects of RIS and fungicide treatments, when combined, were not additive. Captan combined with RIS stimulated less rooting than would be expected from the separate effects of the chemicals. Dichlone and RIS interacted positively to improve rooting.

RIS treatment improved rooting in three of four rooting environments tested. There was no effect in the section with bottom heat that was hand watered. Misting was not necessary to get adequate rootings of treated cuttings. Misting appeared to enhance rooting if the rooting bench was heated, but was unnecessary if it was not. These inferences relative to rooting environment must, howev be viewed with some skepticism. Since rooti environments were not replicated, there is no way to te whether the results were due strictly to the treatmer or some confounding factor, such as location.

Of the four factors examined in the study, only R treatment had a significantly positive effect on rootir. Fungicide application either had no real effect (dichlon or a distinctly negative effect (captan) on rooting succes. Purple sage cuttings may be rooted easily by treating wi RIS and placing them in unheated rooting benche. Treating cuttings with the fungicide dichlone a supplying mist may improve rooting success.

Cuttings from one plant exhibited significantly grea rooting over all treatments (51 percent) than cuttin from the other three plants (15 to 22 percent). Apparent, certain individuals in the population from which the stu plants were selected have a distinctly greater ability to ro from cuttings. If such differences are genetic rather th environmental, increased rooting of purple sage cuttin may be obtained by selecting plants for cutting sto that have a greater inherent ability to root.

Table 1.--Mean percent of cuttings rooted by treatment

No bottom heat with mist		
RIS (NAA/IBA)[1]	Captan	[2]15^{b}
	Dichlone	77^{a}
	None	63^{a}
No RIS	Captan	4^{b}
	Dichlone	10^{b}
	None	6^{b}
No bottom heat, no mist		
RIS	Captan	27^{b}
	Dichlone	75^{a}
	None	67^{a}
No RIS	Captan	6^{b}
	Dichlone	8^{b}
	None	6^{b}
Bottom heat with mist		
RIS	Captan	[3]17
	Dichlone	50
	None	46
No RIS	Captan	6
	Dichlone	31
	None	33
Bottom heat, no mist		
RIS	Captan	[3]10
	Dichlone	17
	None	13
No RIS	Captan	10
	Dichlone	23
	None	13

[1]RIS: root inducing substance (a 50-50 mix [w/w]) of naphthaleneacic acid (NAA) and indolebutyric acid (IBA).

[2]a means are separated from *b* means by Hartley's sequential metho of testing, 5 percent level.

[3]No significant difference in rooting among the six treatments, 5 per nt level.

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Formatting and Documenting Multidisciplinary Data

Joyce A. Schlieter[1]

ABSTRACT

The management of data accumulated during the course of a 5-year multidisciplinary research program is discussed. A system developed for organizing collected data is described and a reference sheet, designed to identify and facilitate data access, is shown.

KEYWORDS: data management, multidisciplinary data, data reporting form

The Intermountain Forest and Range Experiment Station Forest Residues Utilization Research and Development (R&D) Program was chartered for 5 years (1974-1979) to investigate: (1) opportunities for reducing the wood volume left as residue following harvest; (2) the biological and environmental consequences of alternative harvesting and intensive utilization practices; and (3) new or expanded markets for currently unused timber resources. Vast amounts of data were accumulated by Program scientists and numerous cooperating researchers as various parts of the above problems were studied.

Most data was generated by program research concerned with environmental and management consequences of harvesting. Some disciplines involved in this portion of the Program were meteorology, hydrology, nutrient cycling, microbiology, entomology, and silviculture. Analyses were carried out in each discipline to obtain first-order responses to harvesting. One of the goals of the R&D Program was to link all or parts of the data from the various disciplines in a fashion that would be directly useful to forest managers. To facilitate analysis and especially to aid in accessing and combining data from different disciplines, an efficient data management system was needed.

Efficient data handling, storage, and analysis required the use of a computer. The available computer system used punched cards as the input medium. An advantage of punched cards was that a permanent backup of the data base was established. The data cards were read into the computer and then were transferred to magnetic tape for storage.

DATA FORMAT

Early in the Program, the decision was made to use a common formatting system for individual disciplines. Each participating researcher was assigned a set of numbers and from these a unique three-digit format code was given to each type of data. For example, in meteorology some of the codes were:

050 --- air temperature
051 --- soil temperature
052 --- precipitation
053 --- solar radiation
054 --- net radiation

Much of the research effort for the Program was concentrated on a single experimental area. A grid of permanent plot points was set up for the area and all observations collected were tied to these permanent plots. A standard card format was then defined (fig. 1) with the first 14 columns set aside for identification. This common identification block makes it easy to cross-reference data from the different disciplines by date and site. A similar system was used for sampling at other experimental areas.

DATA DOCUMENTATION

The next step in the management of the data was to develop a system for documentation. This was important for several reasons. At the termination of the Program, some of the scientists involved either were moved to other locations or were assigned to other research projects. They were no longer immediately available for advice and consultation, even though continuing analysis and modeling work will be underway for some time. In addition, the data base accumulated during the Program's life contains a vast amount of information that might be of potential value to other researchers.

[1]The author is mathematical statistician stationed at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

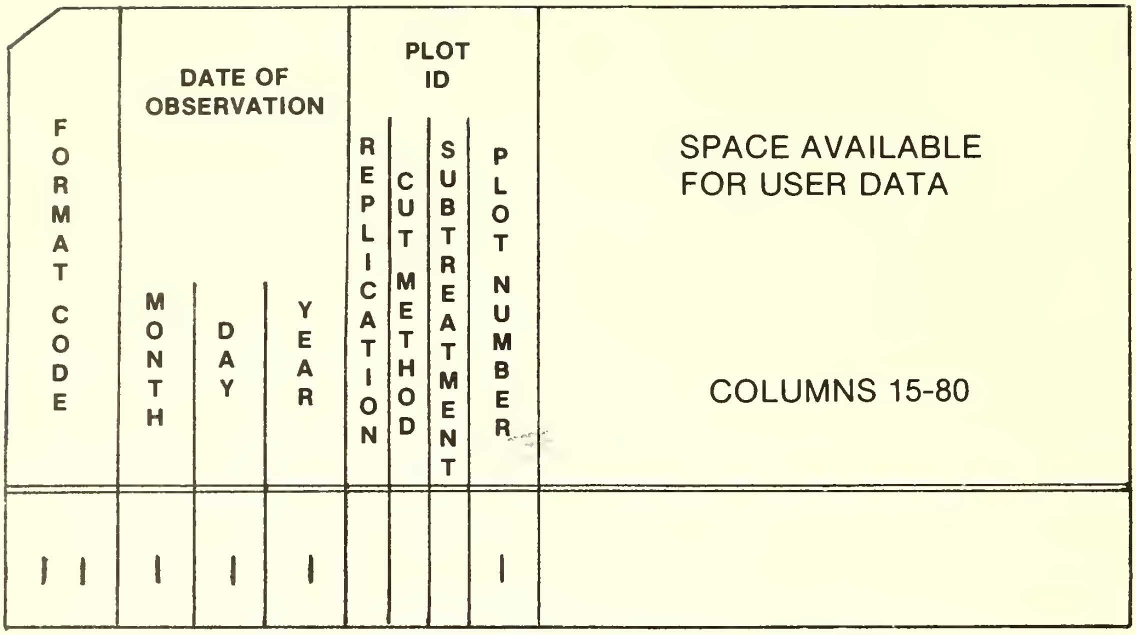

Figure 1.--Data card design for the Forest Residues R&D Program.

A data reporting form was designed to meet these documentation needs. Each researcher provided information on the sampling procedure used, the dates of sampling and the card layout (an example is given in fig. 2). The sheets were compiled in looseleaf notebooks under six categories: fauna, residues, soils, vegetation, meteorology, and hydrology. This reference system will aid any future user of the R&D data base.

LONG-TERM DATA STORAGE

Since the end of the R&D Program, an effort has been made to identify the data likely to be in demand for further analysis. These data are currently being stored on a nine-track, high density tape (6250 bits/inch) at the LBL Computer Center in Berkeley, Calif. This storage medium was chosen because of its reliability and accessibility. Data files not available on the tape are available on cards.

Each file on the master tape is identified by a pathname. These pathnames will be listed on the data reporting form. For example, the pathname for the data described in figure 2 would be:

JOYCE/DATA/METEOR/HUNGER/PRECIP/
CORAM/F 052

This pathname, the card layout information from the data reporting form, and the tape number are all one would need to access and use the data.

DISCUSSION AND RECOMMENDATIONS

This method for formatting and documenting multidisciplinary data was the approach taken by **one** research program. Data management and analysis requirements will rarely be the same for two research endeavors. In 1974 when the Program began, time, as well as personnel and available computer facilities, limited the options. If the Pro gram were starting now, different methods might b employed.

The heavy dependence on cards for data entry proved t be costly and time consuming. In 1977, data acquisitio equipment was installed on two experimental areas fo recording meteorological measurements on cassette tape The information on these cassette tapes was then trans ferred directly to magnetic tape and a computer routin was used to translate the data into the original forma (fig. 1).

The use of an available data base management system i another option that would warrant examination. Most suc systems are designed for business and accounting applica tions, but there have been attempts to handle research dat (Anderson and Cohen 1976; Anderson 1977). An advantag to such a system would be that information could be re trieved without requiring the services of a computer pro grammer. Often there are lengthy delays in obtaining de sired analyses due to a lack of programing assistance. A disadvantage of using an existing data management sys tem would be the costly computer resources and personne required for implementation. If the computer center bein accessed had a system available, however, there would b no additional computer expense. Personnel specificall trained in data management should be available becaus experienced statisticians are not necessarily "experts" i the field of computerized data management (Helms 1978).

Documentation is the foundation of a sound data man agement system. Through the data reporting form an ac curate and complete record of all the information collecte can be maintained. The long-term data storage method allow easy retrieval of the data files. These procedure designed and used by the R&D Program could be adapte to other similar research investigations.

FOREST RESIDUES R-D PROGRAM DATA REPORTING FORM

TYPE OF DATA: Meteorology (Precipitation) **FORMAT CODE:** 052

PRINCIPAL INVESTIGATOR: Roger Hungerford

LOCATION: Coram

GENERAL INFORMATION:

Tipping bucket rain gages that recorded events every 0.01 inch of moisture were used. The orifice is 8 inches in diameter. A 7-day drum chart recorder was used to record events. Rain gages were set on the ground surface or on a low stump within 25 feet of the weather shelter. Rain gages were set out in May each year and removed for the winter in November.

DATES OF SAMPLING:

Station:	**12**	**14**	**21**	**23**
Date Started:	6/13/75	9/20/73	8/18/74	6/1/74
Date Off:	Continuing	9/30/77	9/30/77	9/30/77

DATA FORMAT:

Columns	*Items*	*Columns*	*Items*	*Columns*	*Items*
1-3	Format code 052	39-42	Precip 1400 X.XX		
4-5	Month	43-46	Precip 1600 X.XX		
6-7	Day	47-50	Precip 1800 X.XX		
8-9	Year	51-54	Precip 2000 X.XX		
10	Replication	55-58	Precip 2200 X.XX		
11	Cut Method	59-62	Precip 2400 X.XX		
12	Subtreatment	64	Code*		
13-14	Plot Number	66-71	Last day missing data		
15-18	Precip 0200 X.XX				
19-22	Precip 0400 X.XX				
19-22	Precip 0400 X.XX				
23-26	Precip 0600 X.XX				
27-30	Precip 0800 X.XX				
31-34	Precip 1000 X.XX	*See code sheet at beginning of Meteorological data			
35-38	Precip 1200 X.XX				

Figure 2.--Sample data reporting form for the Forest Residues R&D Program.

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PATTERN--A System for Land Management Planning

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ABSTRACT

Describes PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers), a procedure for identifying and ranking key factors in land management decisions. Applies the technique to a hypothetical example.

KEYWORDS: planning, land management, priorities

INTRODUCTION

Land use and land management planning have become an ever-increasing concern since the beginning of the environmental movement of the early 1960's. The National Environmental Policy Act of 1969 (NEPA) added emphasis to this topic with its restrictions and directives. Since the adoption of this landmark legislation, additional regulations such as the Environmental Quality Improvement Act of 1970, Clean Air Act Amendment of 1970, and the Federal Water Pollution Control Act Amendment of 1972 have added even more directions and controls. Moreover, two additional laws, the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) and the National Forest Management Act of 1976 (NFMA), provide additional direction for land use and land management planning activities. Both pieces of legislation specify interdisciplinary planning and public input. All of these directives have contributed to the already complex process of planning and allocating.

In the early 1960's, Honeywell's[2] Military and Space Sciences Department developed a normative forecasting technique called PATTERN (**P**lanning **A**ssistance **T**hrough **T**echnical **E**valuation of **R**elevance **N**umbers) based on a mission-oriented *relevance tree* (Esch 1969). The relevance tree technique has been an aid in industry for identifying critical areas that required attention. Several other authors have also discussed and applied this forecasting technique in industrial situations (Gordon and others 1973; Jantsch 1968; Martino 1972). More recently this procedure has been applied in the outdoor recreation field (Shafer and others 1974; Shafer and Morrison[3]). This latter study was aimed at determining social and physical variables important in determining recreation management decisions. The technique was also used in integrating fire management and land management planning (Barney 1976).

As Shafer and Morrison[3] pointed out, PATTERN was originally developed and used most extensively for planning in the military sector; however, the methodology can be applied to other subject areas where decisions must be made and priorities must be determined. Furthermore, it seemed reasonable that PATTERN could be used to identify the most relevant factors in areas like resource allocation, fire management, and land management planning. The procedure helps isolate and set priorities for key elements in the planning and decision process.

This paper tells how to use PATTERN as a planning tool. PATTERN can be used by both the planner and the public. The specifics of the process are discussed and examples are shown. Additional readings are suggested for those who care to pursue the technique.

THE PATTERN PROCESS

How PATTERN functions is illustrated through an example adopted from Bright (1974). The original example provided more detail; however, this adaptation provides the basic elements.

To utilize PATTERN, we must first set an objective. Let us assume our objective is to purchase the best car for transportation needs. We begin by describing the situation and factors that might influence the eventual choice.

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[2]The use of trade, firm, corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

[3]Shafer, Elwood L., Jr., and Douglas A. Morrison. 1969. Some relevant factors for selecting recreation-development decisions. Unpubl. study plan on file at USDA For. Serv. Northeast. Exp. Stn., Broomall, Pa. 17 p.

Our situation might go like this: James and Mary Walsh have two children, 10 and 13 years old. James is a GS-12 engineer for the USDA Forest Service. His office is 20 miles from home. The home is located 10 miles from the school and 8 miles from the major shopping center. The family is outdoor oriented--skiing, camping, fishing, and hunting. They have a dog that often travels with them. The car they are driving now is 11 years old and needs a major overhaul. James spends 1 hour each day traveling to and from work. He needs a car that is easy to handle for all weather and road conditions. He is interested in a car with low maintenance, because his free time is limited and he is dependent on the car for transportation. Because of this dependency, he has decided to replace the car every 3 years; so he wants a car that will also have a good trade-in value.

This briefly covers the Walsh's situation. You should be able to picture the needs and desires for transportation. To use PATTERN you must first construct what is called a relevance tree. To keep the example simple, we will forego several options that could be developed in this tree. A simple relevance tree might look like figure 1. We have purposely limited the number of automobile makes and models. In actual practice, these choices can be limited because of availability, agreement of concerned parties, or by the fact that these might be the reasonable choices. Once the tree has been developed, we can present it in matrix form or table (fig. 2).

The axes of the matrix have special names: first-order and second-order relevance components. First-order relevance components are the most important items to consider and are listed down the left-hand column of the matrix. The user ranks each first-order component on a percentage basis according to its importance to the objective *within* the confines of the situation described. Second-order relevance components are those listed along the horizontal axis of the matrix. In either case rankings are based on the importance to the person making the ranking as related to the overall objective. The scores are developed by ranking on a percentage basis the second-order (horizontal items) relevance components as they relate to the first-order component of that row in the matrix.

The objective of this specific example is to select the best car for the situation. The features listed in figure 2 were taken from the situation and the relevance tree; the car models are those from which Mr. Walsh is prepared to make a choice. Figure 3 shows how Mr. Walsh filled in the relevance tree matrix. (Percentage values are entered in the matrix as decimals for ease of calculation.) He ranked mileage and handling as the two most important features, followed by maintenance; least important were comfort and resale.

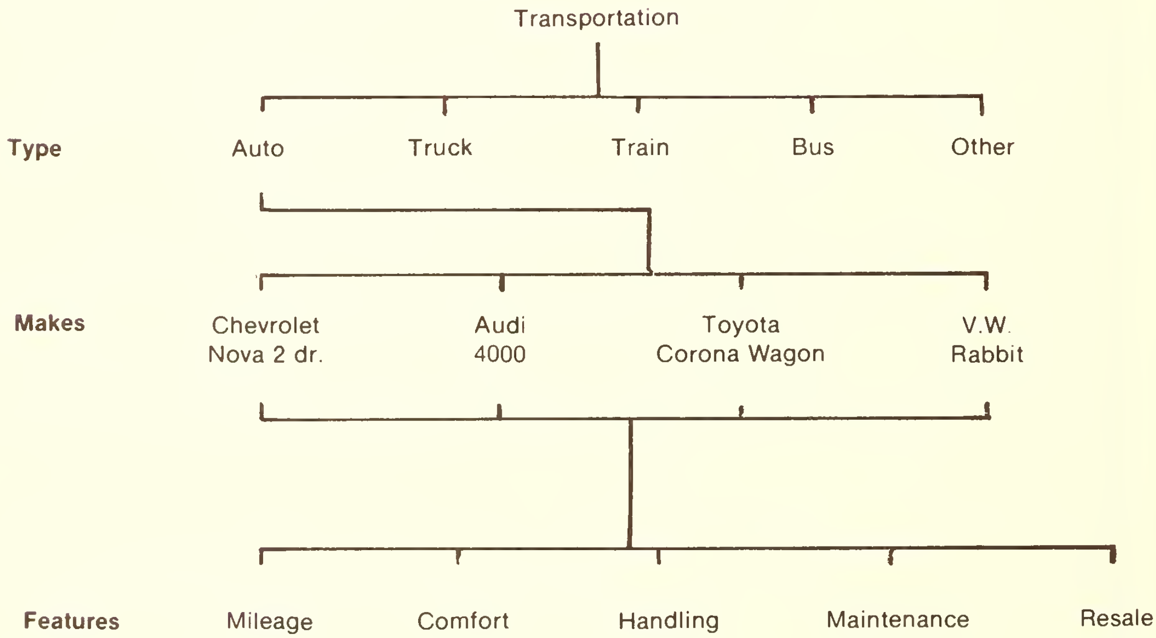


Figure 1.--A simple relevance tree.

Feature	Chev. Nova	Audi 4000	Toyota Corona Wagon	V.W. Rabbit
Mileage				
Comfort				
Handling				
Maintenance				
Resale				

Figure 2.--Relevance tree in matrix form.

Feature		Chev. Nova	Audi 4000	Toyota Corona Wagon	V.W. Rabbit	Total
Mileage	(0.30)	0.10	0.30	0.20	0.40	1.00
Comfort	(.10)	.20	.30	.25	.25	1.00
Handling	(.30)	.20	.30	.20	.30	1.00
Maintenance	(.20)	.40	.20	.20	.20	1.00
Resale	(.10)	.25	.25	.25	.25	1.00
Total	(1.00)					

Figure 3.--Mr. Walsh's completed relevance matrix, unadjusted scores, entered as decimals.

Now to fill in the second-level score. Walsh ranked each car model with respect to a particular feature. Looking at figure 3 again, we see that the car models, with respect to mileage, ranked: V.W. Rabbit, Audi 4000, Toyota Corona wagon, and Chevrolet Nova. Walsh ranked each car equally with respect to maintenance, except the Nova, which he apparently felt had twice as good a record for repairs. The resale potential was ranked equally for all models. Remember, this was Walsh's ranking; yours might be quite different. Each of these second-level relevance score row totals must total 100 percent.

Now that the input has been developed and the relative importance of each first-order and second-order component determined, we adjust the relevance scores. We first compute an adjusted relevance matrix. This is done by multiplying the first-level scores times the second-level scores of the same row in figure 3. For example, using the first row mileage, you would multiply 0.30 x 0.10 = 0.03, 0.30 x 0.30 = 0.09, 0.03 x 0.20 = 0.06, etc. Figure 4 illustrates the results of this adjustment procedure. Adding the appropriate row products and column products also provides a check on your arithmetic. The sum of the row totals (0.30 + 0.10 + 0.30 + 0.20 + 0.10) must be 1.00 or 100 percent, and the sum of the column totals (0.215 + 0.275 + 0.21 + 0.30) must also be 1.00 or 100 percent. From this adjusted relevance score matrix, we are able to develop averages, bar graphs, rank orders, and other related statistics to assist the decision process.

If each member of the Walsh family had prepared relevance tree, we could develop an average tree l combining each matrix and determining an avera percentage for each cell or square. The combined matr would then represent the family's attitude regarding the c purchase.

As shown in figure 4, the total relevance score in the righ hand column should equal the first-level scores determin in figure 3, and the column should total 100 percent or 1.0 The totals for each column will also add up to 100 percent 1.00. Based on the adjusted relevance data used here, t V.W. Rabbit ranked first; the Audi 4000, second; t Chevrolet Nova, third; and the Toyota Corona Wagon, la This order might have changed if all the family data h been used or if you had done the ranking. Nevertheless t does quantify how James Walsh feels about the situatio Within the relevance matrix, we can identify tho combined items that have the higher adjusted relevan scores. For example, Rabbit/mileage was highest with 0. Audi/mileage, Audi/ handling, and Rabbit/handling we second with 0.09. The value, itself, is not as important as relationship to the other values in the matrix. The combin scores illustrate some of the important internal compone that make up the total values. Remember, these data do t provide the decision--people do. The data do, howev provide quantitative input into the decision process, wh can be very helpful. The data also help identify tho components and combinations of components that important, and rankings of components.

Feature	Nova	Audi	Corona	Rabbit	Total
Mileage	0.03	0.09	0.06	0.12	0.30
Comfort	.02	.03	.025	.025	.10
Handling	.06	.09	.06	.09	.30
Maintenance	.08	.04	.04	.04	.20
Resale	.025	.025	.025	.025	.10
Total	**.215**	**.275**	**.21**	**.30**	**1.00**

Figure 4.--Adjusted relevance scores.

LAND MANAGEMENT APPLICATION

The Walsh's car purchase demonstrated how PATTERN works. To apply the system to land planning, we could utilize the same general sequence of events outlined in the car example. First of all, we need an objective for the specific land area in question. We would also need a statement outlining the planning situation, including available resources, area being considered, and outputs expected. A separate statement should be developed for each planning alternative anticipated in the planning activity. In the following example, the alternatives and the statements will be purposely less complete than they might be in a real planning situation. Nevertheless, these examples should indicate how the process might be used in land planning.

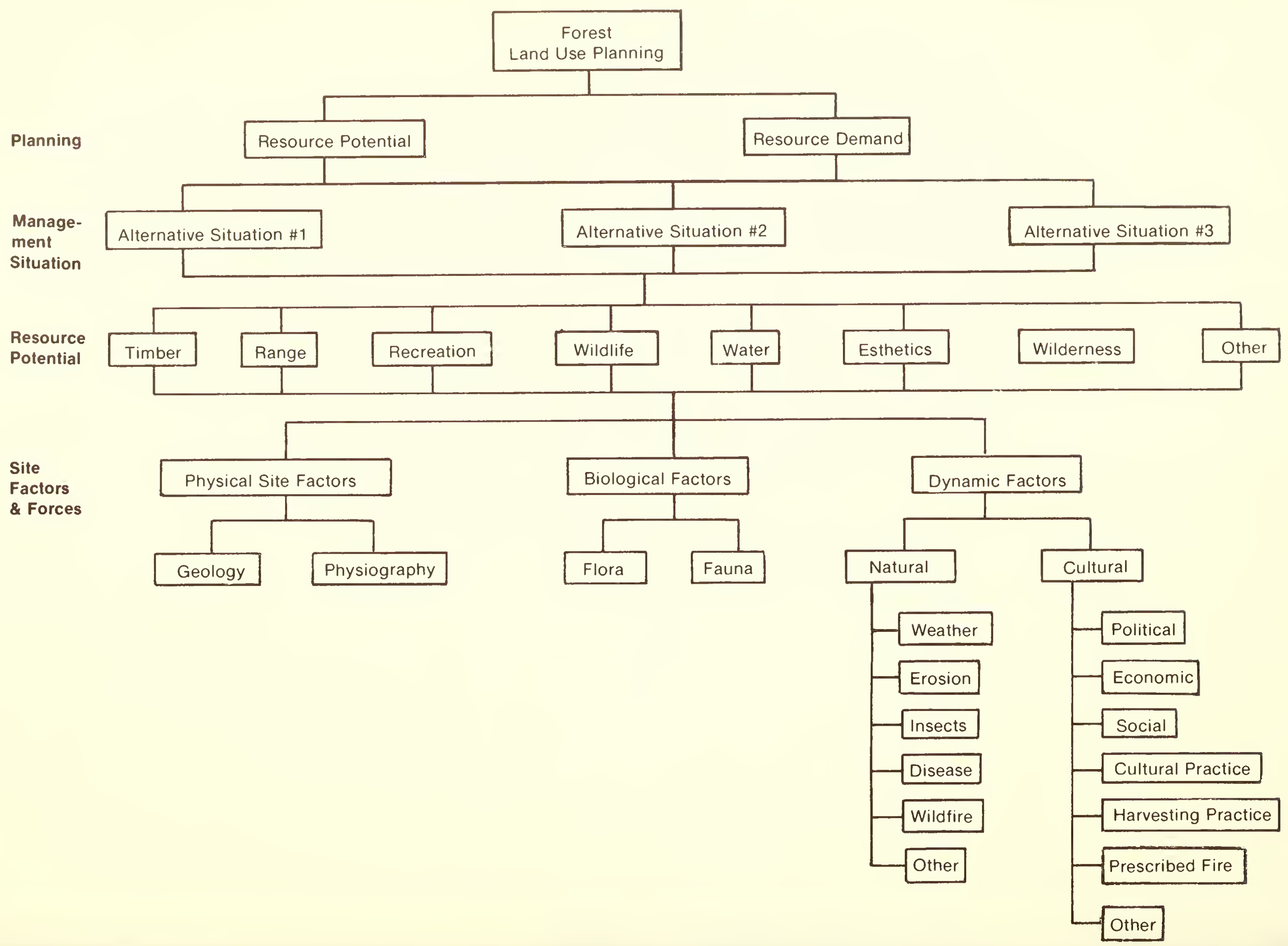
Our general statement might go like this: you are developing a multiple-use management program for an undeveloped roadless area. The area is several townships in size, with virtually no developed access. It is adjacent to an established wilderness area. Potential resources include timber, wildlife, water, range, and recreation. One management alternative emphasizes timber and wildlife, with the use of other resources as appropriate. A second management alternative emphasizes wildlife and recreation, with modest utilization of timber, and utilization of remaining resources as appropriate. The third management alternative considers wilderness the primary management objective.

Having outlined the general situation and three broad management alternatives, we can proceed to utilize PATTERN in our planning. Again, as in our example for purchasing a car, we must develop the relevance tree for ranking the importance of various components. Figure 5 depicts a relevance tree for our situation. Several variations on this basic relevance tree certainly could have been developed; however, we decided that we would discuss resource potential for the planning area, which includes the traditional values, and then the site factors and forces that change resource flows, depending upon how they are developed. We therefore must consider basic site factors, basic biological factors, and dynamic forces that affect the site and biological components.

Our relevance tree then can be converted from the form shown in figure 5 to a matrix as shown in figure 6. As can be seen in figure 6, the matrix considers only resource potential and site factors and forces. This matrix can be utilized for each of the planning alternatives outlined above, and provide input in balancing resource potential and resource demand. After all, this balancing is planning. We are trying to harmonize the utilization of the biological and physical potential of an area, as dictated by demand, in some form of management strategy. The document resulting from this balancing exercise, providing direction to the land manager, is the management plan.

Our example shows the relevance tree converted into a two-dimensional decision matrix (fig. 6). The horizontal axis represents forest resource potential. The vertical axis represents the various site factors. Again, as illustrated in our earlier example on car procurement, each cell in the matrix will eventually be assigned a relevance score or percentage by each participant. Each of these relevance scores indicates the participant's perception of the relative importance of the items of the matrix as they relate to each of the planning alternatives.

You may develop any number of relevance trees, depending upon the specific situation. A relevance tree is most effective when each item in the tree is mutually exclusive of the others. Extreme interdependence makes it difficult to make decisions and rank the individual items. All components of the tree should be defined so there is no question as to the intent or the meaning of the specific terms.


Forest
Land Use Planning
Planning
Resource Potential
Resource Demand
Manage-
ment
Situation
Alternative Situation #1
Alternative Situation #2
Alternative Situation #3
Resource
Potential
Timber
Range
Recreation
Wildlife
Water
Esthetics
Wilderness
Other
Site
Factors
& Forces
Physical Site Factors
Biological Factors
Dynamic Factors
Geology
Physiography
Flora
Fauna
Natural
Cultural
Weather
Erosion
Insects
Disease
Wildfire
Other
Political
Economic
Social
Cultural Practice
Harvesting Practice
Prescribed Fire
Other

Site factors and forces (summed vertically)	Forest Resource-Potential (summed laterally)								
	Timber	Range	Recreation	Wildlife	Water	Esthetics	Wilderness	Other (specify)	Total
Geology and physiography	+	+	+	+	+	+	+		= 100%
+ Flora and fauna	+	+	+	+	+	+	+		= 100%
+ Erosion	+	+	+	+	+	+	+		= 100%
+ Insects and disease	+	+	+	+	+	+	+		= 100%
+ Wildfire	+	+	+	+	+	+	+		= 100%
+ Political and social forces	+	+	+	+	+	+	+		= 100%
+ Economics	+	+	+	+	+	+	+		= 100%
+ Management practices	+	+	+	+	+	+	+		= 100%
+ Prescribed fire	+	+	+	+	+	+	+		= 100%
+ Other (specify)	+	+	+	+	+	+	+		= 100%
Total = 100%									

Figure 6.--General relevance tree matrix with site factors and forces in first-order position.

AN OPERATIONAL EXAMPLE

Let us suppose you want to use this technique in your land management planning. It might be useful within the interdisciplinary team to develop individual and team values. The tool could also be used with special interest groups as an objective means for quantifying relative values.

Once the planning objectives are developed along with the situation description, the general procedures for PATTERN are outlined to the group. A very simple example of PATTERN might be presented to the group, perhaps similar to the car example. Work a sample exercise, allowing enough time to insure that everyone understands the process. This example can be used to show participants how relevance trees are developed and relevance values are determined. Before moving into a land management PATTERN exercise, answer all questions. Based on our own experience, this introductory exercise is well worth the time.

Upon completion of the sample exercise and question period, the real exercise can begin. All participants can be told something similar to the following:

> Review the situation statement and the planning alternatives. Remember, decisions are usually made using an array of inputs. The relevance tree may not be all inclusive. Inputs from several other individuals and sources and feedback may be desirable. However, your general responses are provided on the basis of the factors considered most important in the planning and management of the described alternative.

The participants can then be told:

> Indicate the relative weights (in percentage) of each of the components for the planning alternative described. Values you assign to the site factors and forces in the left-hand column should total 100 percent. (These values are called *first-level* relevance scores.) It is not necessary to have numbers in each cell; some cells may be left blank and will be treated as if zeros had been entered. If zeros are entered in the left-hand column, the appropriate row must also be left blank.

The second step requires each decisionmaker to:

> Evaluate the resource potentials that are outlined in the body of the relevance tree matrix. Then indicate the relative weights of each of these factors *within* the bounds of *each* of the site factors. All values you assign to items within each resource-potential site factor should total 100 percent. These are the *second-level* relevance scores.

Relevance Trees, General Concerns

Relevance values are sometimes in error. Sometimes values do not total 100 percent. When the row or column does not add up to 100 percent, a normalization procedure may be used. This procedure determines the relative weight of each cell in the row or column and then assigns a new value for each cell (keeping the same relative weight for each cell) so the total equals 100. For example: (0.25 + 0.15 + 0.20 + 0.20 + 0.10 + 0.20 = 1.10). Normalized to 1.00 or 100 precent the values would be (0.227 + 0.136 + 0.182 + 0.91 + 0.182 = 1.00).

Conversion of Raw Scores

Second-level values for a first-level category are multiplied by that first-level category score. This procedure adjusts all second-level scores throughout the relevance tree matrix so that they total 100 percent. Figure 7 shows a relevance tree matrix like figure 6 completed by a participant. First, the left-hand column (first-level relevance score) was filled into total 100 percent vertically. Secondly, the horizontal rows (second-level scores) were considered within the item in the left-hand column and were completed so each row totals 100 percent horizontally.

Combining Relevance Tree for Each Planning Alternative

For each planning alternative, an *average* relevance tree can be computed for all participants by desired groupings. The average relevance tree can be developed by averaging the *adjusted* second-level scores within each cell of the matrix. Each cell's adjusted total score for all participants is divided by the total number of respondents in the specified grouping. Figure 8 is an example of an average adjusted relevance score matrix representing 339 individuals combined

	Site factors and forces (summed vertically)	Forest Resource-Potential (summed laterally)								
		Timber	Range	Recreation	Wildlife	Water	Esthetics	Wilderness	Other (specify)	Total
10 +	Geology and physiography	10 +	5 +	10 +	5 +	20 +	35 +	15 +	0	= 100%
15 +	Flora and fauna	40 +	30 +	10 +	10 +	5 +	5 +	0 +	0	= 100%
10 +	Erosion	20 +	5 +	5 +	0 +	20 +	40 +	10 +	0	= 100%
5 +	Insects and disease	40 +	20 +	20 +	10 +	0 +	10 +	0 +	0	= 100%
10 +	Wildfire	20 +	10 +	10 +	15 +	20 +	20 +	5 +	0	= 100%
10 +	Political and social forces	15 +	15 +	10 +	10 +	5 +	5 +	40 +	0	= 100%
15 +	Economics	40 +	10 +	20 +	5 +	15 +	5 +	5 +	0	= 100%
20 +	Management practices	30 +	10 +	10 +	15 +	15 +	20 +	0 +	0	= 100%
5 +	Prescribed fire	20 +	10 +	10 +	25 +	25 +	5 +	5 +	0	= 100%
0	Other (specify)	0 +	0 +	0 +	0 +	0 +	0 +	0 +	0	= 100%
Total = 100%										

Figure 7.--An example of an individual's completed relevance tree matrix.

Site F/F	RESOURCE POTENTIAL								
	Timber	Range	Recreation	Wildlife	Water	Esthetic	Wilderness	Other	Total
GEO/PHYS	0.0115	0.0090	0.0285	0.0112	0.0233	0.0274	0.0030	0.0009	0.1149
FLO/FAUN	.1040	.0138	.0338	.0263	.0194	.0317	.0029	.0006	.1425
EROSION	.0125	.0108	.0196	.0066	.0318	.0194	.0013	.0011	.1031
INS/DIS	.0124	.0038	.0101	.0067	.0045	.0134	.0009	.0004	.0521
WILDFIRE	.0152	.0082	.0201	.0136	.0210	.0267	.0017	.0009	.1154
POL/SOC	.0204	.0132	.0498	.0210	.0263	.0364	.0044	.0011	.1725
ECONOMIC	.0128	.0106	.0279	.0096	.0171	.0147	.0018	.0010	.0956
MGT PRAC	.0184	.0136	.0363	.0207	.0268	.0324	.0027	.0012	.1522
RX FIRE	.0066	.0058	.0069	.0096	.0077	.0098	.0008	.0003	.0470
OTHER	.0012	.0007	.0010	.0005	.0006	.0006	.0002	.0001	.0048
Total	.1249	.0680	.2418	.1257	.1785	.2124	.0198	.0078	1.0000

Figure 8.--Adjusted average relevance scores for a matrix involving 339 respondents.

Interpreting Summaries and Comparisons

Up to this point you have been exposed to the process of PATTERN, the relevance tree, the matrices, and the adjusted relevance score. How does the planner use it? What possibilities does it have in helping you to do your job? As mentioned previously, PATTERN does *not* make decisions. PATTERN provides an assembly of information that is additional input to the decision process, which eventually becomes the final plan. It helps quantify, in an objective manner, some of the values important to people.

By applying PATTERN to each planning situation and its alternatives, you may compare the various scores to see changes in importance of values and change in perceptions by the same group. This change of importance then can help you weigh factors that enter into your management alternatives or your selection of a final management strategy. You can tie public issues to the kind of information presented in the example shown in the previous few pages. This is only an example and the relevance tree must be tailored to your own specific situation. Nevertheless, the relevance tree used in our example might fit your planning situation.

Let us reexamine figure 8. Here is an example of adjusted relevance scores for a large data base for a relevance tree matrix similar to the one outlined in this paper. These are the raw values. The totals at the bottom show that recreation ranked first; esthetics ranked second; water, third. Timber and the other traditional commodities were ranked below these. Therefore, you could use these scores when comparing the alternatives as seen by the participants. The site factors and forces most important to the participants are reflected in the largest values in the right-hand column. This may or may not be important, depending upon the management action alternatives for the area. It may be important, however, in determining the kind of management action for the area and help the manager make a decision.

You can also consider the highest value of each cell within the matrix and see the major combined factors that made up the totals. Referring back to the car purchasing exercise may show how you might apply the combined factors of interest. Working with data as outlined in figure 8 is one approach. It is sometimes difficult to work the raw numbers. The four decimal places as in figure 8 do not necessarily indicate great precision. The importance is not the value itself, but the relative difference of the value compared to other values. We cannot really distinguish between the importance of a 0.0240 as compared to a 0.0268.

Sometimes it is helpful to categorize the data and stratify them in bigger components or "chunks." Some people have preferred quartile breakdowns. Data are stratified by ranges in which one-fourth of the data is in the upper set, one-fourth in the lower set, one-fourth in the upper middle and one-fourth in the lower middle. Figure 9 represents a quartile breakdown of data presented in figure 8. The bottom of the table indicates the ranges of the relevance scores for each quartile, for example the upper quartile ranges from 0.0204 through 0.0498. The sum of the individual relevance values within those upper quartile cells is equal to 57.65; this tells us that more than 57 percent of all the value ascribed to all the cells in that matrix falls into the upper quartile, so it is fairly important.

In this case the 4 and 3 indicate which quartile the cell belongs in. The quartile diagram represents values as stratified into larger groups. If you use a quartile diagram for each of the planning situations and alternatives, you may see a shift in the position of the upper-middle, lower-middle and lower items. This helps identify the shift of issue importance by planning situation. This procedure can be used for linking information with the issues identified by the publics.

In reviewing the quartile summary example, the 20 most important items (upper quartile) account for 57.65 percent

	SITE FACTORS AND FORCES							
Res Potn	Timber	Range	Recreation	Wildlife	Water	Esthetic	Wilderness	Other
GEO/PHYS	3	2	4	3	4	4	2	1
FLO/FAUN	3	3	4	4	3	4	2	1
EROSION	3	3	3	2	4	3	1	1
INS/DIS	3	2	2	2	2	3	1	1
WILDFIRE	3	2	4	3	4	4	2	1
POL/SOC	4	3	4	4	4	4	2	1
ECONOMIC	3	3	4	2	3	3	2	1
MGT PRAC	3	3	4	4	4	4	2	1
RX FIRE	2	2	2	2	2	2	1	1
OTHER	1	1	1	1	1	1	1	1

	QUARTILE:	UPPER	UPPER MIDDLE	LOWER MIDDLE	LOWER
		4	3	2	1
Sum of the percentages within each quartile		57.65	28.72	12.08	1.55
Range of percentages within each quartile		0.0498-0.0204	0.0196-0.0106	0.0101-0.0017	0.0013-0.0001

Figure 9.--Average relevance tree quartile summary and statistics, 339 respondents.

of the total adjusted values. The upper and upper-middle quartiles combined account for 86.37 percent of the total (fig. 9). Resource Potential Factors, Recreation, Esthetics, and Water provide the greatest share of the upper quartile values. In terms of Site Factors and Forces, however, Political and Social Forces and Management Practices appear to be the leaders. Individual factors, Political and Social Forces, Management Practices, Flora and Fauna, and Wildfire ranked 1 through 4, respectively, for this example.

The top five combined factors (fig. 8) account for 18.87 percent of the total relevance tree. This means 6 percent of the cells are accounting for about 20 percent of the importance. The items scoring in the top five in descending order are:

1. Political and Social Forces/Recreation
2. Political and Social Forces/Esthetics
3. Management Practices/Recreation
4. Flora and Fauna/Recreation
5. Management Practices/Esthetics.

The quartile summary for this situation shows a clustering of upper quartile values. The upper quartile accounted for over 50 percent of the total tree.

Critical Decisions

Our use of PATTERN has illustrated the respondents' opinions of important considerations for one planning alternative. Agreement and disagreement can be identified among, between, and within various respondent stratifications. These relevance tree data provide the interacting priorities for the management alternatives presented. In our example, 25 percent of the adjusted relevance scores accounted for approximately 50 percent of the entire relevance tree value. Pooling data for all respondents tends to to mask the diversity found on a stratified basis. The smoothing further tends to hide internal differences.

Data generated by this technique can tell managers and planners how others view alternatives. These kinds of data can also help indicate important constraints in various situations. Through a more complete understanding and a more objective evaluation of important factors, planners and managers can better evaluate activities as well as better understand the public perceptions.

The relevance trees, quartile diagrams, and other types of data stratification depict the respondents' concepts of the various relationships of pertinent factors. As indicated by Shafer and others (1974), this type of analysis can also be helpful in developing decision games for evaluating the consequences of various alternatives. Furthermore, results can be used for determining changes in attitude in the future.

The technique used, PATTERN, appears to be useful for developing individual management plans. The process provides an objective procedure to assess, order, and eventually integrate multiple factors in a two-dimensional matrix. Planning teams can use such a procedure to quantitatively assess their posture or the position of various publics on various planning issues for which relevance trees can be constructed. Individuals outside of planning might also be included in the process, especially in situations of great diversity of opinion. The process allows developing an objective analysis of some subjective information. PATTERN is another tool to assist in the task of planning.

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**Intermountain
Forest and Range
Experiment Station**

Research Note
INT-319

August 1981

Trends in Recreational Use Of National Forest Wilderness

Margaret Petersen[1]

ABSTRACT

Trends in recreational use are useful as predictors of the need for future management decisions. As more land has been added to the National Forest Wilderness System, increases in use have occurred primarily on areas established by 1965. Visitor use of the areas designated by 1965 has been increasing at an average rate of 4 percent per year.

KEYWORDS: wilderness, wilderness use, trends in visitor use

INTRODUCTION

Information about the amount of wilderness recreational use is important for better wilderness management. Trends in use are particularly important as predictors of the need for future management decisions. This reseach note presents trends in visitor use for the National Forest portion of the National Wilderness Preservation System during the period 1965-80. The land size of the Wilderness System has grown during this period, particularly in the last 5 years. Reported increases in recreational use include both use intensity and wilderness acreage. In this analysis, wildernesses are grouped by year of designation and trends in visitor use are identified for each group of areas. This allows increased use on previously designated areas to be evaluated separately from increases resulting from additions to the wilderness land base.

The recreational use estimates used in this report (obtained from the annual reports of the Forest Service) begin with 1965. Prior to this date use was tallied in man-days and visitor days and man-days are not comparable nor convertible with any precision. A visitor day is 12 hours of use from any combination of users. A man-day is essentially one person for a day of the week; however, it becomes complex when handling fractions of days.[2] The estimates include both wilderness and primitive areas because the primitive areas did not differ significantly from the wildernesses, and were undergoing study for wilderness classification. Shifts within the 1965 base (from primitive to wilderness designation) are not noted as new additions to the Wilderness System.

Accuracy of the use estimates is unknown and it probably varies from area to area. Sharp changes in yearly use for individual areas may reflect changes in estimating procedures rather than actual changes in use. They could also reflect weather fluctuations and, possibly, closures due to fire hazard. Examining the data reveals some substantial fluctuations over the 15-year period. Provided that there is no nationwide tendency to under- or overestimate use, year-to-year variations for particular wildernesses should have little effect on systemwide trends.

[1]Research forester, located at Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

[2]Hendee, John C., George H. Stankey, and Robert C. Lucas. 1978. Wilderness Management. USDA For. Serv. Misc. Publ. 1365. Washington D.C.

RESULTS AND DISCUSSION

Visitor use of the areas designated by 1965 has almost doubled, increasing 82 percent over 15 years (table 1)! This represents an average increase of over 4 percent per year.

By 1980 over 8 million additional acres (3.2 million ha) had been added to the 14.6 million National Forest wilderness acres (5.9 million ha) established by 1965. It was not until 1979 (fig. 1) that recreational use within the added wilderness areas became appreciable. Even then, the additions accounted for only 10 percent of the total use. In 1978, 96 percent of the total use occurred on the original areas; by 1980 the original areas accounted for 88 percent. However, this 88 percent of total use occurred on only 65 percent of the National Forest Wilderness System acreage. Changes in total visitor-day use after 1978 reflect adding land areas with significant amounts of use, although these areas account for only 12 percent of the total. The 15 areas added to the system in 1979 have more total use than all the other areas designated since 1965 combined. Thus, there is a trend for wilderness additions to account for an increasing percentage of the total use. Because of their nature, most recent wilderness additions may contribute little to this trend, however. For example, in December 1980, 5.4 million Alaskan acres (2.2 million ha) were added to the National Forest Wilderness System. Because of the vast size and remoteness of these areas, they will likely continue to be lightly used.

A frequent assumption is that recreational use increases after an area is designated "wilderness" because of the appeal of the name. Although no use data are available for the period immediately before designation, the use of new wilderness areas in their first few years of existence may partially illuminate the effect of designation. Areas designated in 1973, 1977, 1978, and 1979 have had higher average annual rates of increase, from 15 to 27 percent, than the 1965 areas (table 1). These increases should be viewed cautiously, however, because they reflect the trends of only one to three wilderness areas for a given year's designation. In 1979 there were 15 new areas, so that only 1 year's change is available. Perhaps the best indicator of a possible trend for changing use after wilderness designation is noted from the 16 eastern wilderness areas established in 1975. The average annual rate of increase for these areas is 6.7 percent (table 1), only 2.4 percent higher than the annual rate of increase for the 1965 areas.

Without any "before wilderness designation" use data it is not possible to measure directly the effect of wilderness designation on recreational use. However, although use of newly designated areas usually increases more rapidly than does use of older areas, it appears that the effect is neither strong nor universal.

Table 1.--Visitor-day use and percentage change (%Δ) of National Forest wilderness in existence from 1965 through 1980 (1973-1979 are the years additions were made; parentheses denote the number of added to the system)

Year	1965	%Δ	1973	%Δ	1975	%Δ	1976	%Δ	1977	%Δ	1978	%Δ	1979	%Δ
1965	4,522,100	--												
1966	4,789,200	5.9												
1967	4,690,100	-2.1												
1968	5,056,500	7.8												
1969	5,071,900	.3												
1970	5,842,800	15.2												
1971	6,703,000	14.7												
1972	6,459,400	-3.6												
1973	6,665,300	3.2	16,400(1)	--										
1974	6,723,000	.9	19,700	20.1										
1975	7,297,100	8.5	15,300	22.3	201,000(16)	--								
1976	6,789,600	6.9	41,400	170.6	253,500	26.1	22,500(1)	--						
1977	7,755,200	14.2	32,900	-20.5	198,300	-21.8	19,000	-15.6	2,900(1)	--				
1978	8,290,900	6.9	33,700	2.4	205,600	3.7	15,600	-17.9	3,100	6.9	62,200(3)	--		
1979	8,651,500	4.4	36,300	7.7	217,200	5.6	22,900	46.8	4,100	32.3	87,100	40.0	585,800(15)	--
1980	8,177,000	-5.5	48,400	33.3	260,500	19.9	22,700	-.9	5,400	31.7	78,500	-9.8	675,300	15.3
Average annual percentage change		4.3		27.3		6.7		3.1		23.6		15.1		15.3

ADDITIONS TO THE NATIONAL FOREST WILDERNESS SYSTEM BY YEAR

1973: Scapegoat

1975: Sipsey, Caney Creek, Upper Buffalo, Bradwell Bay, Cohutta, Ellicott Rock, Beaver Creek, Presidential Range-Dry Creek, Joyce-Kilmer Slick Rock, Gee Creek, Bristol Cliffs, Lye Brook, James River Fall, Dolly Sods, Otter Creek, Rainbow Lake

1976: Hells Canyon

1977: Hercules Glade

1978: Manzano Mountains, Sandia Mountains, Fitzpatrick

1979: Golden Trout, Kaiser, Santa Lucia, Gospel Hump, Hunter-Fryingpan, Indian Peaks, Great Bear, Welcome Creek, Chama River Canyon, Wenaha-Tucannon, Wild Rogue, Lone Peak, Blackjack Springs, Whisker Lake, Savage Run.

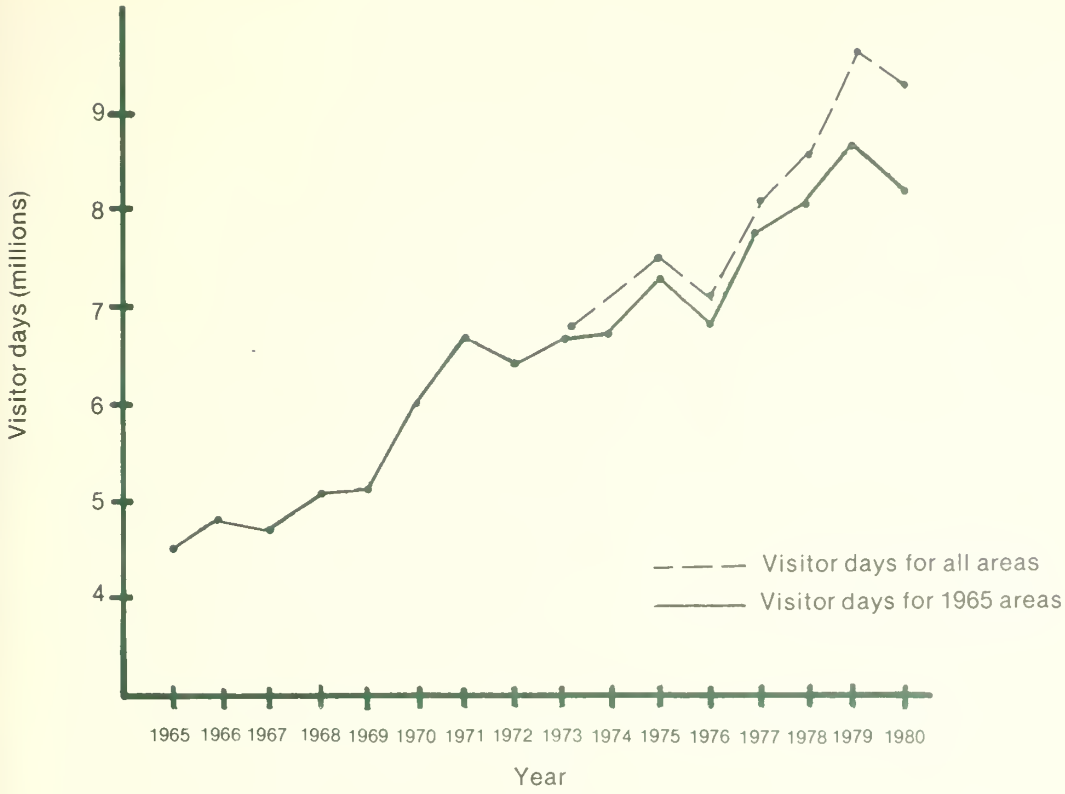

Figure 1.--Trends in recreational use for base 1965 wilderness and primitive areas from 1965-80.

CONCLUSION

The change in total use of National Forest wilderness from 1965 through 1980 is due primarily to increases in use intensity on the original areas existing in 1965. It is not until 1978 that the first substantial increases due to the increasing land base are evident. Even so, 88 percent of the total visitor-day use in 1980 occurred on the 1965 areas that comprised only 65 percent of the total National Forest wilderness acreage.

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Research Note
INT-320

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The Effect of Brush Competition and Plastic Mulch on Moisture Stress of Planted Douglas-fir

Jonalea R. Tonn and Russell T. Graham[1]

ABSTRACT

The effect of black plastic mulch and brush competition on seedling plant moisture stress, soil temperature, and survival was investigated on a 30-acre (12-ha) south-facing brushfield in a *Pseudotsuga menziesii* var. *glauca/Physocarpus malvaceus* habitat type at the Priest River Experimental Forest. No significant differences ($p \leq 0.05$) in mean plant moisture stress were detected among seedlings planted under brush, mulched with plastic, or planted in the open. Slope position did not affect seedling plant moisture stress but did affect soil temperatures. Significant differences were detected for both plant moisture stress and temperature over the growing season. Survival rates among the treatments were not different at the end of the first growing season. Brush competition on the site did not cause moisture deficits in the planted seedlings but did provide habitat for hares (*Lepus* sp.) that, in turn, caused extensive damage.

KEYWORDS: Moisture stress, black plastic mulch, brush competition, Douglas-fir, rodent damage

[1]Forester and research forester, respectively, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

Approved for publication by Intermountain Station December 1981

INTRODUCTION

Warm, dry, southerly exposures are often difficult to regenerate after disturbance by wildfires or harvesting. These sites may be invaded by shrubs, grasses, and forbs that compete with new seedlings. If conditions are not favorable, planting often fails. Plant moisture stress (PMS) indicates water available for plant processes and, as such, is an excellent indicator of the physiological condition of a seedling. Low levels of PMS (below 10 bars) indicate that seedlings are receiving adequate moisture for photosynthesis, transpiration, and other metabolic processes. High levels, above 20 bars, indicate seedlings are having difficulty absorbing water rapidly enough to keep up with transpiration. Maximum photosynthesis in Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) occurs when PMS is below 10 bars. Douglas-fir seedlings die when PMS is greater than 50 bars (Cleary and others 1978). The objective of this study was to determine how brush and black plastic mulch affect seedling survival, soil temperature, and plant moisture stress of newly planted Douglas-fir seedlings.

STUDY AREA AND METHODS

The experiment was established in a 30-acre (12-ha) south-facing brushfield in the *Pseudotsuga menziesii/ Physocarpus malvaceus* habitat type (Daubenmire and Daubenmire 1968) on the Priest River Experimental Forest in northern Idaho. The most prevalent shrub species were: *Acer glabrum, Ceanothus sanguineus, Symphoricarpos albus, Holodiscus discolor, Prunus emarginata, Physocarpus malvaceus, Amelanchier alnifolia, Rosa gymnocarpa, Philadelphus lewisii, Berberis repens, Sambucus caerulea, Salix scouleriana, Rubus parviflorus, Prunus virginiana, Lonicera ciliosa, Clematis columbiana,* and *Rhamnus purshiana*. Shrub heights ranged from 2 ft to 8 ft (0.6 m to 2.4 m). The area was broadcast burned and initially planted in 1968 with subsequent plantings in

1972 and 1976; all plantings were unsuccessful. In the spring of 1980, 2-0 Douglas-fir seedlings were planted at the rate of 600 trees per acre. The study area was divided into three blocks with three treatments per block. Block 1 occupied the upper portion of the slope, block 2 was the mid-slope area, and block 3 was the lower portion of the slope.

The treatments were randomly assigned as:

Brush: Seedlings were planted under the brush with no brush clearing.

Mulch: Brush was removed from a 3-ft by 3-ft (0.9-m by 0.9-m) area, a seedling was planted, then a 3-ft by 3-ft (0.9-m by 0.9-m) sheet of black plastic mulch was placed around the seedling.

Open: Seedlings were planted in a 3-ft by 3-ft (0.9-m by 0.9-m) open area, free from brush.

Plant moisture stress and soil temperature readings were taken at five different dates from May 14 to October 27, 1980. To allow the seedlings time to acclimate, the first measurements were delayed until 30 days after planting. Variables measured on each date were: predawn plant moisture stress (by placing a branch in a Scholander[2] pressure chamber) (Scholander and others 1965), soil temperature at a depth of 12 inches (30.5 cm), and daily precipitation readings. In the fall of 1980, surviving seedlings were counted and rodent damage was recorded.

ANALYSIS

The data were analyzed as a split-block design with three blocks, three treatments, and five time periods. Duncan's multiple range test was used to determine significant differences among mean values.

RESULTS

Plant Moisture Stress

Brush competition and plastic mulch appeared to have no influence on plant moisture stress of the planted Douglas-fir seedlings. No significant differences ($p \leq 0.05$) in PMS means for seedlings planted under brush, under plastic, or in the open could be detected. Seedlings in the brush, mulch, and open treatments had PMS means of 9.8 bars, 10.5 bars, and 10.5 bars, respectively (table 1). Slope position also had no significant effect on seedling PMS. Seedlings growing on the mid-slope had the lowest PMS mean (9.8 bars). The next lower PMS mean (10.1 bars) occurred in seedlings on the upper portion of the slope, and the highest PMS mean (10.9 bars) occurred in seedlings on the lower slope. In contrast, significant differences in PMS were detected throughout the growing season. The highest PMS mean (17.3 bars), which was significantly different than the PMS means for the other dates, occurred at the beginning of the growing season (May). The October PMS mean of 7.3 bars, which was similar to the PMS means for July and September, was the lowest (fig. 1).

Table 1.—Plant moisture stress means by slope position and treatment

Treatment	Slope position: Upper	Mid	Lower	$\bar{X}$	
	Bars				
Brush	9.1	9.9	10.6	9.8	A[1]
Mulch	10.8	10.1	10.5	10.5	A
Open	10.5	9.5	11.5	10.5	A
$\bar{X}$	10.1	9.8	10.9	10.3	
	A[1]	A	A		

[1]Identical letters indicate no significant differences ($p \leq 0.05$)

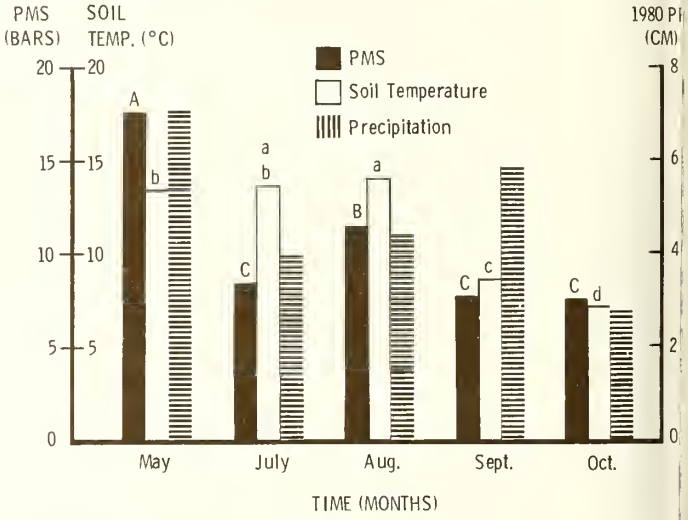

Figure 1.—Means for plant moisture stress, soil temperature, and 1980 precipitation (at the Priest River Experimental Forest) throughout the growing season. (Different letters above bars indicate significant differences [$p \leq 0.05$].)

Soil Temperature

No significant differences in temperatures of soils under black plastic mulch, under brush cover, or in the open could be detected. Soil temperature means for all treatments were between 51° F and 53° F (10° C and 12° C) (table 2). Soil temperatures among slope positions were all significantly different. Soil temperature means on the upper slope, mid-slope, and lower slope were 51° F, 52° F, and 53° F (10.6° C, 11.1° C, and 11.7° C), respectively.

Mean soil temperatures were significantly different throughout the growing season. Soil temperature means for July and August were 56° F and 57° F (13.3° C and 13.9° C), respectively, and were significantly different than the mean soil temperatures of 47° F and 45° F (8.3° C and 7.2° C) for September and October (fig. 1). Also, the soil

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

temperature means for September and October were significantly different from each other and from the other soil temperature means.

Table 2.—Mean soil temperature by slope position and treatment

Treatment	Upper	Mid	Lower	$\bar{X}$	
	Slope position				
	Degrees F (Degrees C)				
Brush	51	52	53	52(11.1)	A[1]
Mulch	51	53	53	52(11.1)	A
Open	51	52	53	52(11.1)	A
$\bar{X}$	51 (10.6) A	52 (11.1) B	53 (11.7) C[1]	(52(11.1)	

[1]Different letters indicate significant differences ($p \leq 0.05$)

Precipitation

The 1980 growing season on the Priest River Experimental Forest was no wetter than normal, but the mid-season months (July and August) had above-normal precipitation (fig. 1). May and September precipitation was also above normal, but below-normal precipitation for June and October averaged out the wetter months. Thus, the mean monthly precipitation of 1.85 inches (4.70 cm) for the 1980 growing season was similar to the long-term mean of 1.83 inches (4.65 cm) per month.

Survival

No differences in survival could be detected among seedlings planted under the brush, with plastic mulch, or in the open. All the treatments had excellent survival with the brush, mulch, and open treatments having survival percentages of 90, 83, and 87, respectively (table 3). Also, no differences in survival rates could be detected among seedlings planted at different slope positions.

Table 3.—Percent survival by slope position and treatment

Treatment	Upper	Mid	Lower	$\bar{X}$	
	Slope position				
	Percent				
Brush	90	90	90	90	A[1]
Mulch	80	90	80	83	A
Open	80	90	90	87	A
$\bar{X}$	83 A	90 A	87 A[1]	87	

[1]Identical letters indicate no significant differences ($p \leq 0.05$)

Damage

During the first growing season, 56 percent of the planted seedlings were damaged by rodents, particularly hares (*Lepus* sp.). Under the brush, 70 percent of the seedlings were damaged. Fifty percent of the trees planted in the open and 47 percent of the trees mulched with plastic were damaged by rodents. Some stem damage was caused by the plastic mulch slipping downslope, but the damage was of little consequence.

DISCUSSION

No differences in plant moisture stress in planted Douglas-fir could be detected among seedlings planted under brush, with plastic mulch, or in the open. Likewise, these treatments did not affect soil temperatures. Slope position had no influence on PMS but did influence soil temperatures. During the growing season, soil temperatures and PMS both changed. At no time, however, did soil temperatures or PMS approach levels critical to the survival of the planted seedlings, probably because of the adequate precipitation that fell during the growing season. If brush does cause a moisture deficit for planted seedlings, it cannot be detected on a droughty site in a year of average rainfall. Even though no significant differences could be detected, the seedlings planted under the brush had the lowest mean PMS.

Brush does provide excellent habitat fcr hares. Seedlings planted under the brush had the greatest rodent damage after the first growing season. Results of an inspection early in the spring of 1981 showed 76 percent of the seedlings were damaged by hares with 16 percent missing from the site. Because of this tremendous amount of damage, the study cannot be continued. The results of this study indicate that, on southerly exposures with moderate brush competition, planted seedlings are in more danger of mortality from rodents than from moisture deficits caused by brush competition.

The plastic mulch prevented ingrowth of shrubs and grasses in the cleared planting spot and helped retain soil moisture. The plastic did not increase soil temperatures nor was it damaging to the stems of the planted Douglas-fir. On warm, dry, southerly exposures, the use of black plastic mulch plus protection from animal damage could be beneficial in ensuring planting success.

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Research Note
INT-321

September 1982

Grizzly Bear Distribution in the Yellowstone Area, 1973-79[1]

Joseph V. Basile[2]

ABSTRACT

Reported sightings of grizzly bears or their sign in the Yellowstone area were compiled for the 1973-79 period and, where sufficient detail permitted, plotted on maps of 10 000 m grid. The 7-year composite of observations probably fairly represents the overall distribution of the grizzly bear. Factors meriting consideration in future monitoring are presented.

KEYWORDS: grizzly bear (*Ursus arctos horribilis*), Yellowstone area

At the start of the 19th century, the grizzly bear (*Ursus arctos horribilis* Ord) was distributed throughout much of arctic and temperate North America from about the 100th meridian to the Pacific Coast (Hall and Kelson 1959). Today, sizable populations still occupy vast expanses of Alaska and western Canada. But grizzlies in the lower 48 states now occupy only a small fraction of their former range and probably number less than 1,000.

The grizzly bear's rapid disappearance from large segments of its early 1800's range, and its decline in numbers, have been well documented (Storer and Trevis 1955; Hall and Kelson 1959; Stebler 1972; Cowan 1972). Diminution of its range and numbers did not result as much from habitat destruction as from the bear's incompatibility with humans. Early settlers considered the grizzly a constant threat to their lives and livestock, and eliminated it from their surroundings. Despite current concerns for the grizzly's survival, present day inhabitants are probably not much more tolerant of the grizzly than the settlers were.

Today's remaining grizzly bear populations owe their existence to the low frequency of bear/human encounters in their present ranges, which in turn stems from the wilderness character of these lands. Remoteness, ruggedness of topography, and costliness of resource exploitation have discouraged human intrusion in the past. However, people have recently penetrated these lands with commercial activities. These inroads, coupled with a high probability of increased exploitation in the immediate future, threaten the bear's remaining sanctuaries.

Forecasts of the grizzly's probable extinction in this century from one of these sanctuaries—the Yellowstone area—led to the formation of an Interagency Study Team to conduct research on the grizzly bear in that area, and to the July 28, 1975, declaration of the grizzly bear as a "threatened species" (Federal Register 40 FR: 31734-31736) pursuant to the Endangered Species Act of 1973.

Despite the decades-old popularily of grizzly bears in the Yellowstone area, no known documentation of their overall distribution existed before the Interagency Study. Because such knowledge is needed for sound management and for complying with provisions of the Endangered Species Act, a monitoring system was begun to determine grizzly bear distribution. This paper presents results of that monitoring from 1973 through 1979.

[1]This paper is a product of the Interagency Grizzly Bear Study, jointly sponsored by the National Park Service, U.S. Fish and Wildlife Service, USDA Forest Service, Idaho Department of Fish and Game, the Wyoming Game and Fish Department, and the Montana Department of Fish, Wildlife, and Parks.

[2]Range scientist located at the Intermountain Station's Forestry Sciences Laboratory, Bozeman, Mont.

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METHODS

Data on bear distribution came from two major sources: observations by study team members, and observations by others as relayed through cooperators. Team observations resulted from:

Aerial reconnaissance from a Piper Supercub. From 1974 through 1976, the major emphasis was on gathering information on bear numbers, sow to cub ratios, and litter sizes; accordingly, as often as weather permitted, flights covered predetermined routes when bears were active in open areas. A shift in emphasis dictated flight patterns from 1977 through 1979 when the major objective was to study movement patterns and habitat use of radio-collared bears. Bears both with and without radios were noted on all flights.

Ground reconnaissance. Field crews traversed approximately 2,800 miles (4 500 km) of trails from 1974 through 1976 seeking evidence of grizzly bears in areas of suspected but heretofore unconfirmed bear use.

Time lapse cameras. Automatic 8 mm movie cameras in weatherproof cases were used at varying types of bait stations to verify the presence of grizzlies in suspected use areas, and as part of a study on bear attractants in the Shoshone National Forest.

Routine field work. All grizzly bear sightings were reported on a standard form, as were sign encountered by team members. Grizzly bear tracks were differentiated from black bear tracks when possible, using criteria listed by Greer and Craig (1971). Scats over 2 inches (5 cm) in diameter were considered those of grizzly bear (Murie 1954).

Observations by persons other than team members were reported by local residents, outfitters, and field personnel of various agencies. These were verified when possible by team members or by other agency personnel.

Each report was classed as either verified (highly probable that it was a grizzly bear and not a black bear) or nonverified (insufficient evidence to judge its validity).

Insofar as possible, locations of observations were designated by Universal Transverse Mercator (UTM) values, and plotted accordingly on maps of 10 000 m grid. Because reports varied greatly in detail, many observations could not be located within the chosen map grid and are omitted from the results given here.

RESULTS

Numbers and distributions of grizzly bear sightings varied considerably from year to year (fig. 1-7). These variations may not be interpreted as reflecting trends in population or shifts in range use within the reporting period. Instead, they reflect the yearly inconsistencies in observability of bears and, more importantly, in the general monitoring scheme. For example, concentrated efforts in selected areas for specific study purposes usually resulted in many observations for 1 or 2 years in those areas, preceded and followed by years of very few or no observations. Too, the willingness of local residents to report grizzly bear sightings waxed and waned according to their imagined consequences of that reporting on their freedom to use grizzly bear range.

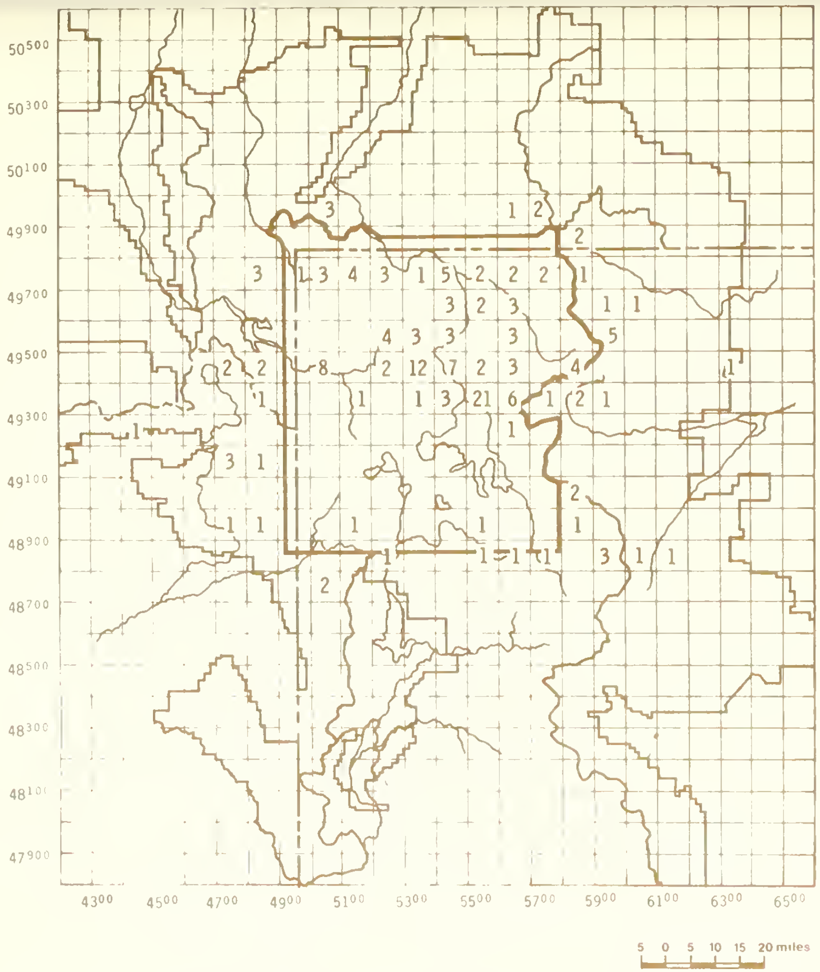

Figure 1.—Numbers of verified sightings of grizzly bears, 1973.

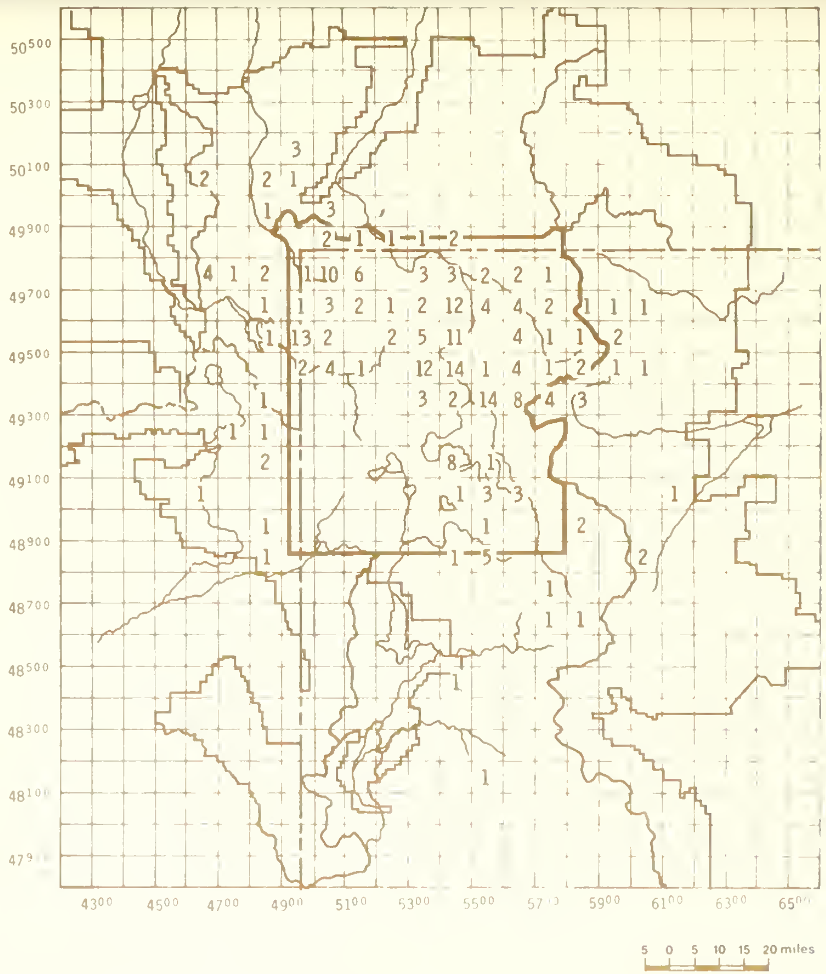

Figure 2.—Numbers of verified sightings of grizzly bears, 1974.

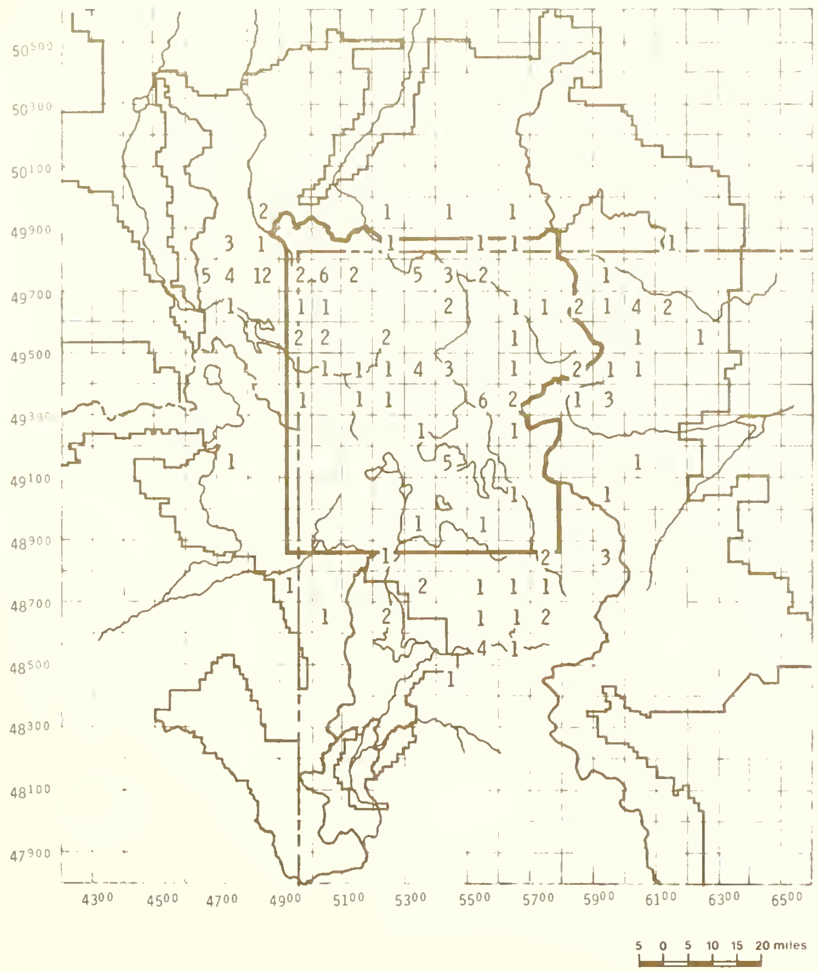

Figure 3.—Numbers of verified sightings of grizzly bears, 1975.

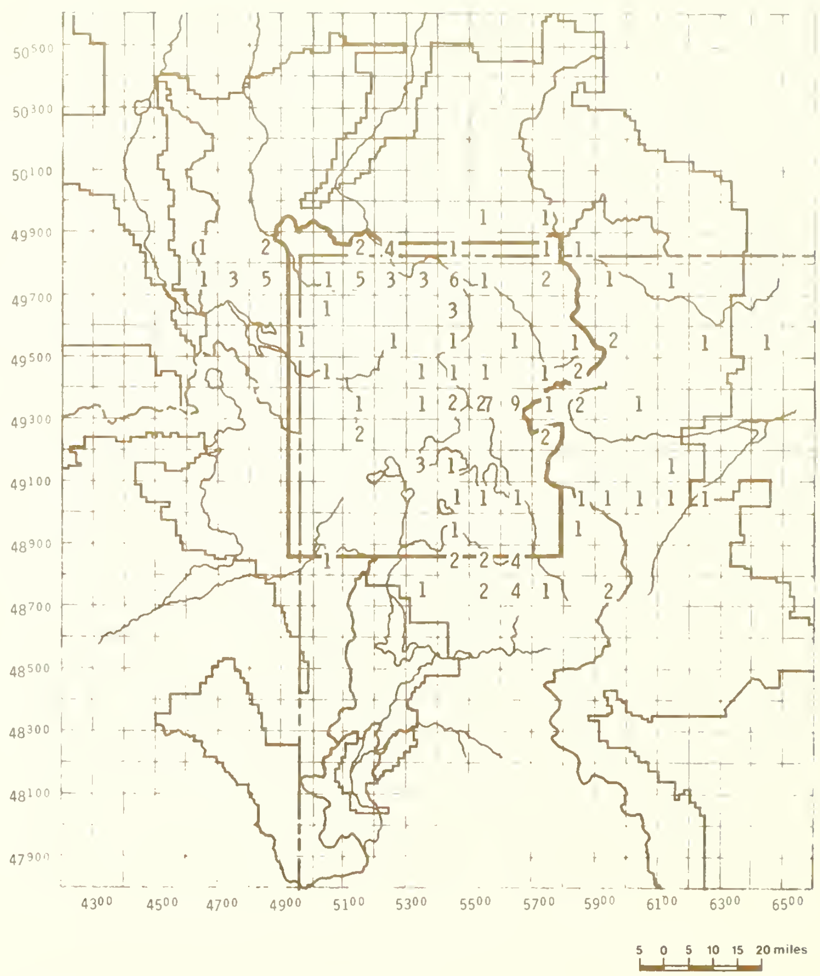

Figure 4.—Numbers of verified sightings of grizzly bears, 1976.

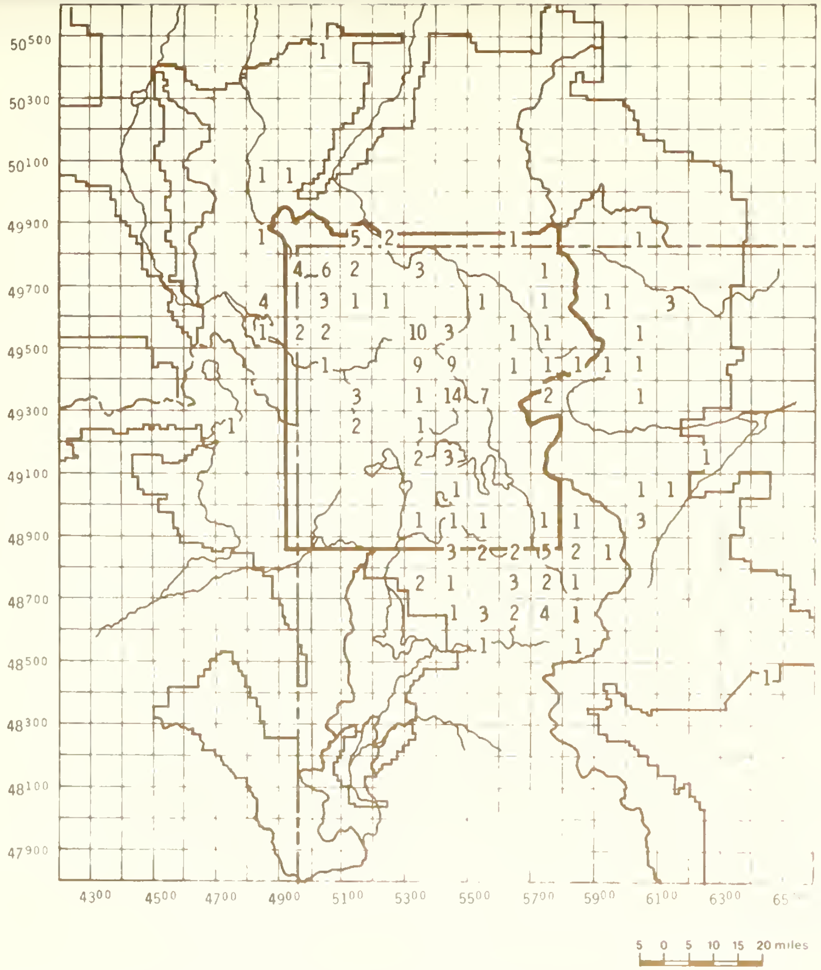

Figure 5.—Numbers of verified sightings of grizzly bears, 1977.

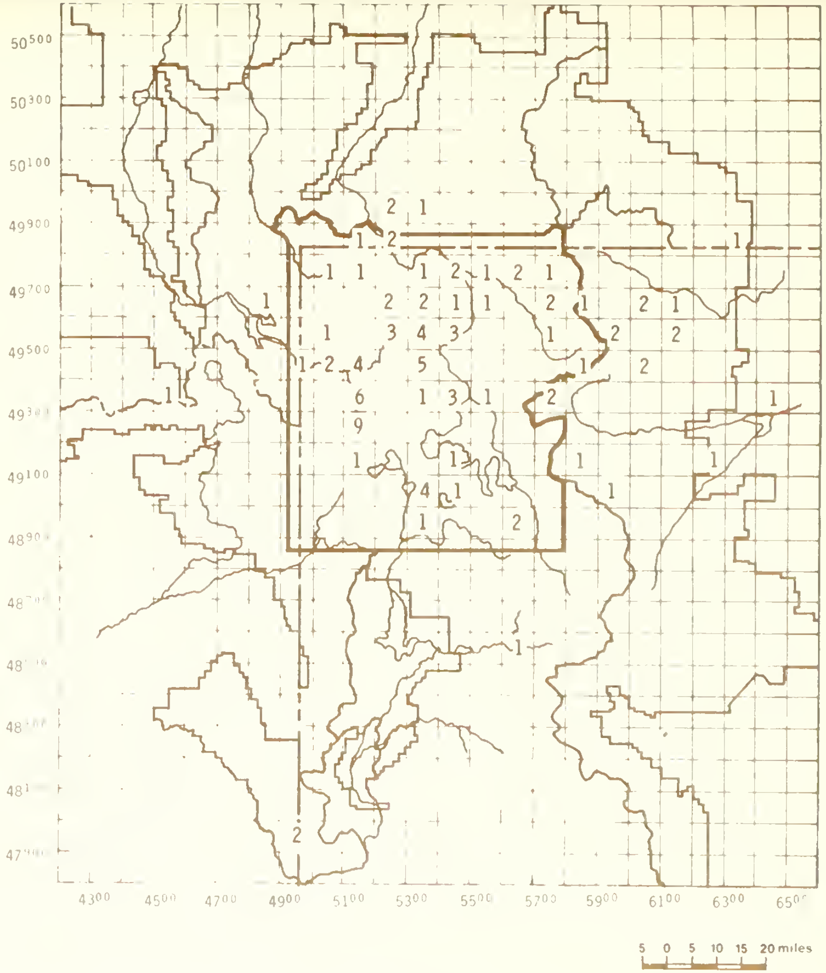

Figure 6.—Numbers of verified sightings of grizzly bears, 1978.

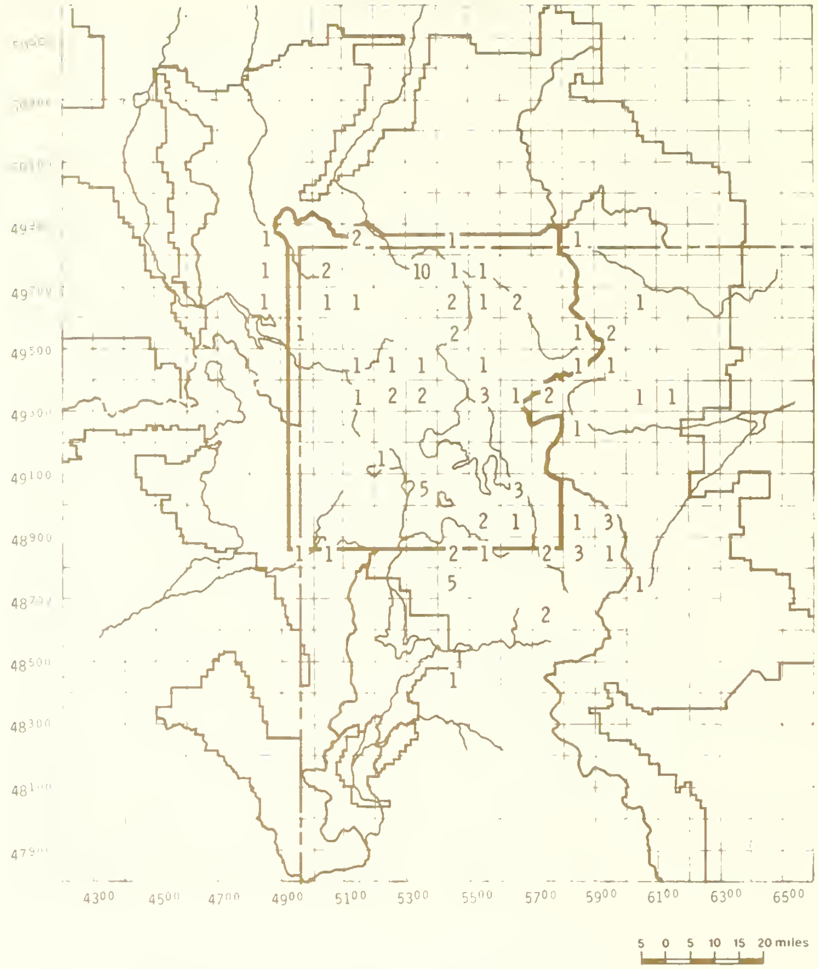

Figure 7.—Numbers of verified sightings of grizzly bears, 1979.

However, the 7-year composite of grizzly bear sightings (fig. 8) tends to smooth these inconsistencies, and when considered in concert with data on constancy of observations (fig. 9), probably represents fairly the overall range of the grizzly. Confidence in this conclusion is strengthened by the general agreement of this composite distribution of sightings with the composite distributions of capture locations (fig. 10), of locations of radio-instrumented bears (fig. 11), and of sightings of females with young (figs. 12 and 13).

Locations of family groups are important because a weaned female tends to establish a home range within the range of its mother, thereby lending some stability to occupation of an area (Pearson 1975). Sightings of family groups, then, provide greater confidence than do sightings of lone bears in delineating occupied areas and in distinguishing chance excursions outside those areas from probable range expansions.

A composite of all verified observations of grizzly bear sign for the 7-year period (fig. 14) does not produce any significant difference in the distribution of bears from that based on sightings (fig. 8). Interestingly, the same overall distribution is noted when all unverified sightings and sign are combined with all verified sightings and sign (fig. 15).

While these composites of observations yield a reasonable representation of occupied range, to detect confidently any future change in that occupancy requires a greater consistency in data collection from year to year. Several factors merit consideration in future monitoring:

Effort. Team monitoring of the geographical distribution of grizzlies should be equal with respect to time, frequency, and intensity of effort, and to area covered. Flights for this purpose should be separated from flights for other purposes.

Sources. Cooperation of the same individuals, or categories of individuals, should be sought each year among agencies, outfitters, stockmen, and local residents.

Reporting. Prompt submission of complete, accurate reports on standardized forms is invaluable, as is adherence to a procedure for verifying reports on grizzlies.

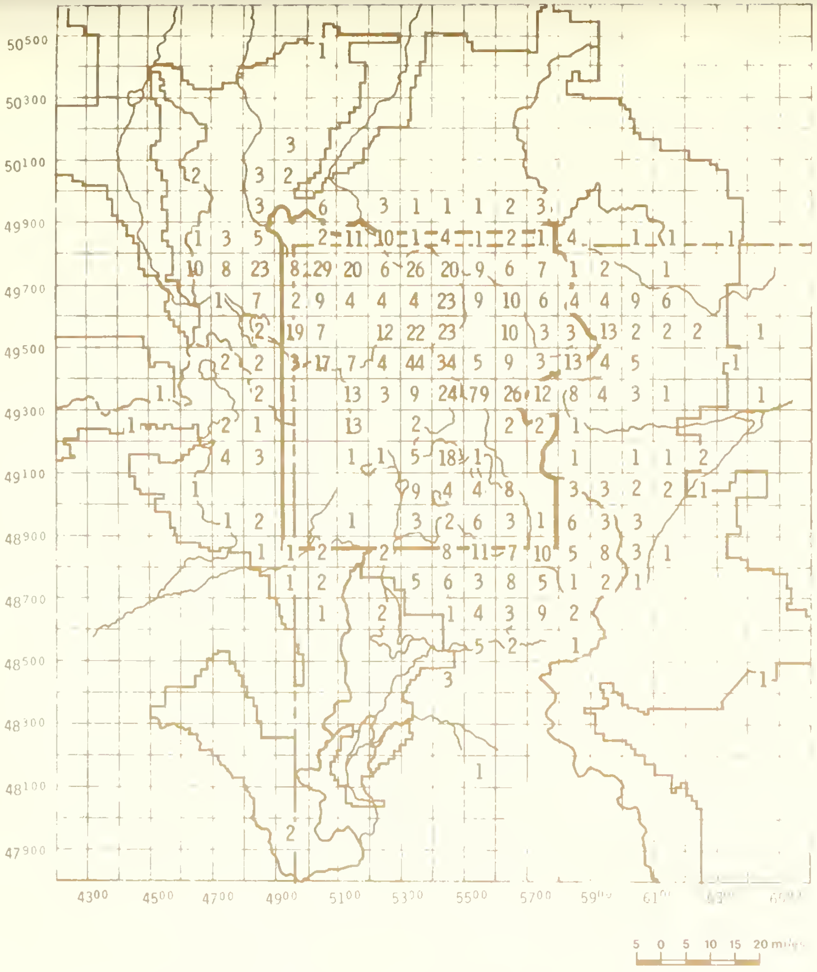

Figure 8.—Composite of verified sightings of grizzly bears for 7-year period, 1973-79

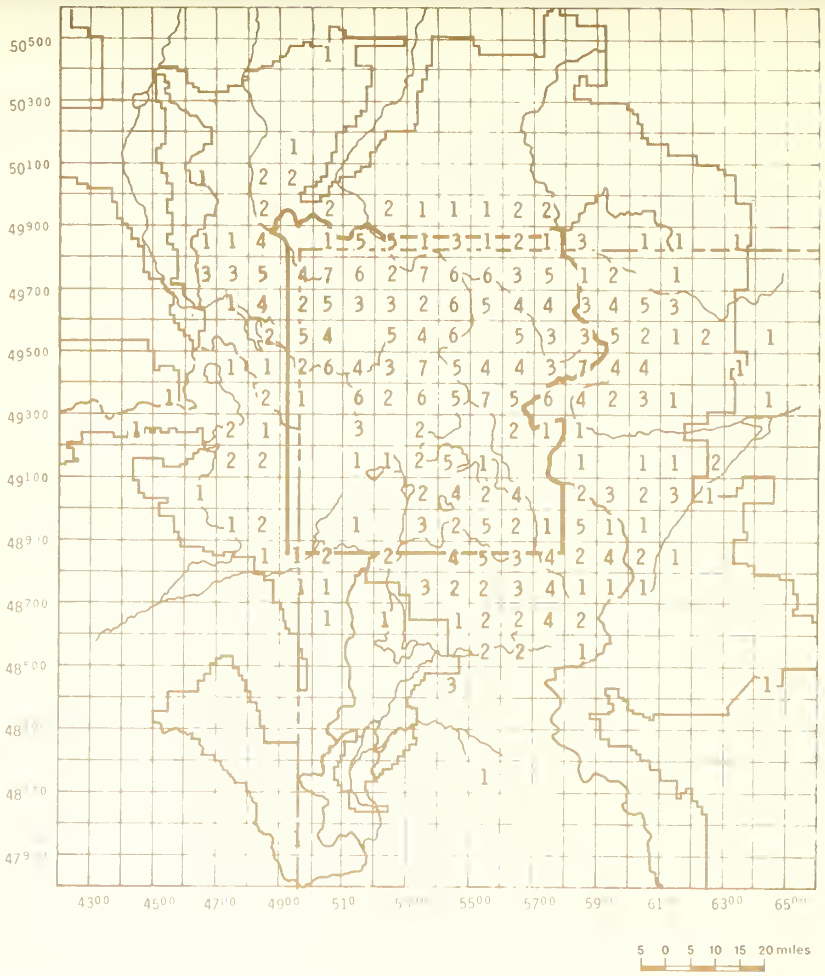

Figure 9.—Numbers of years in the 1973 through 1979 period that verified sightings of grizzly bears were reported

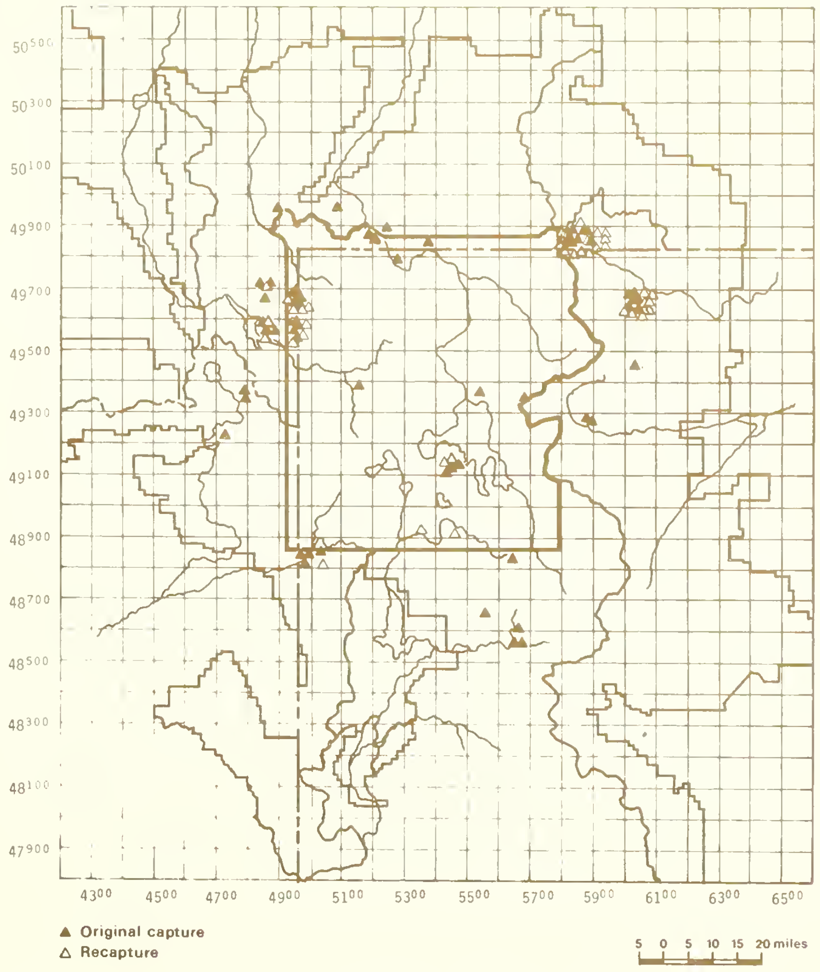

Figure 10.—Original capture and recapture locations of grizzly bears, 1974-79.

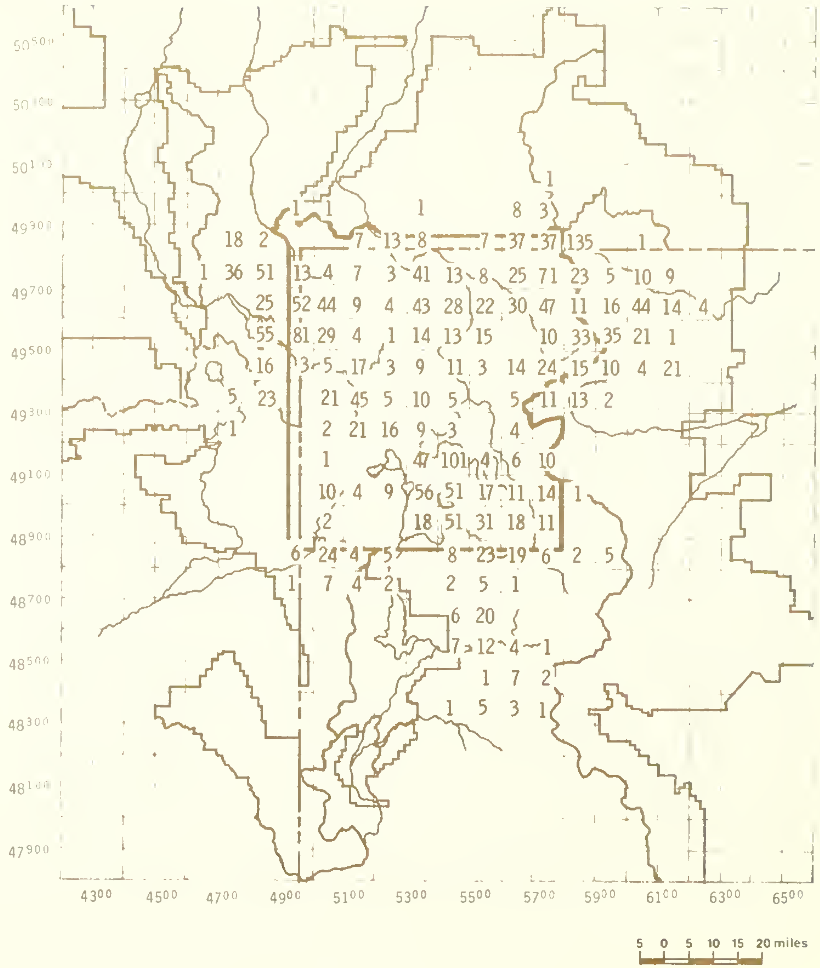

Figure 11.—Numbers of locations of radio-instrumented grizzly bears, 1975 through 1979.

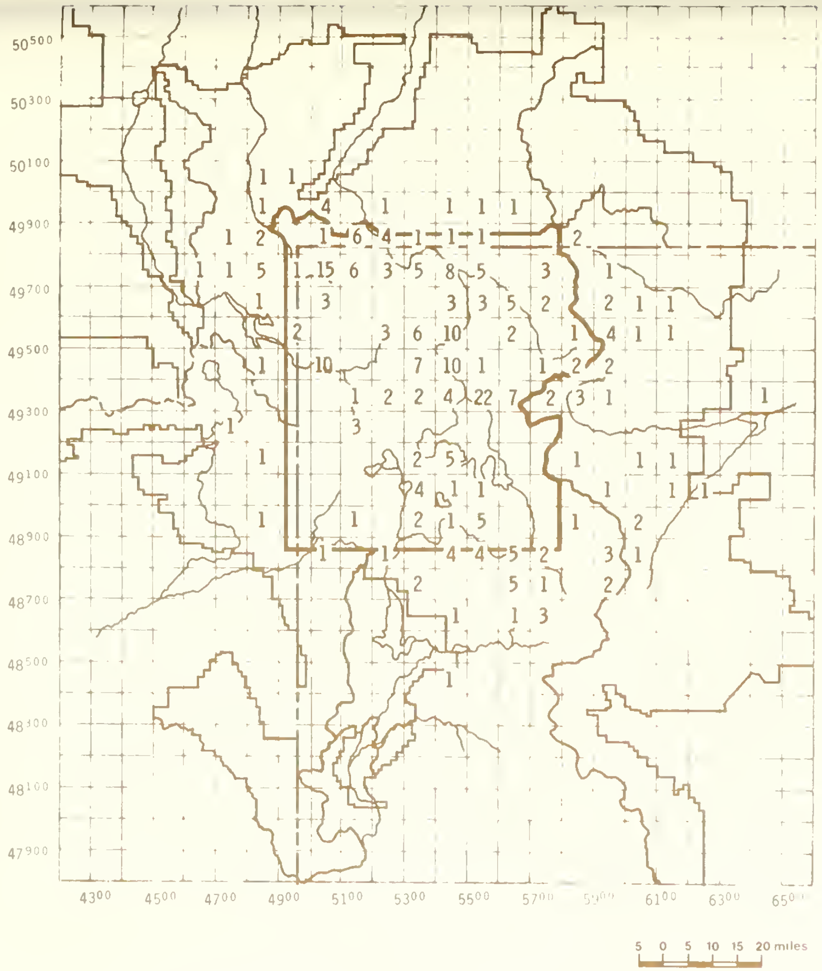

Figure 12.—Composite of verified sightings of female grizzly bears with young, 1973 through 1979 (does not include radio-instrumented bears).

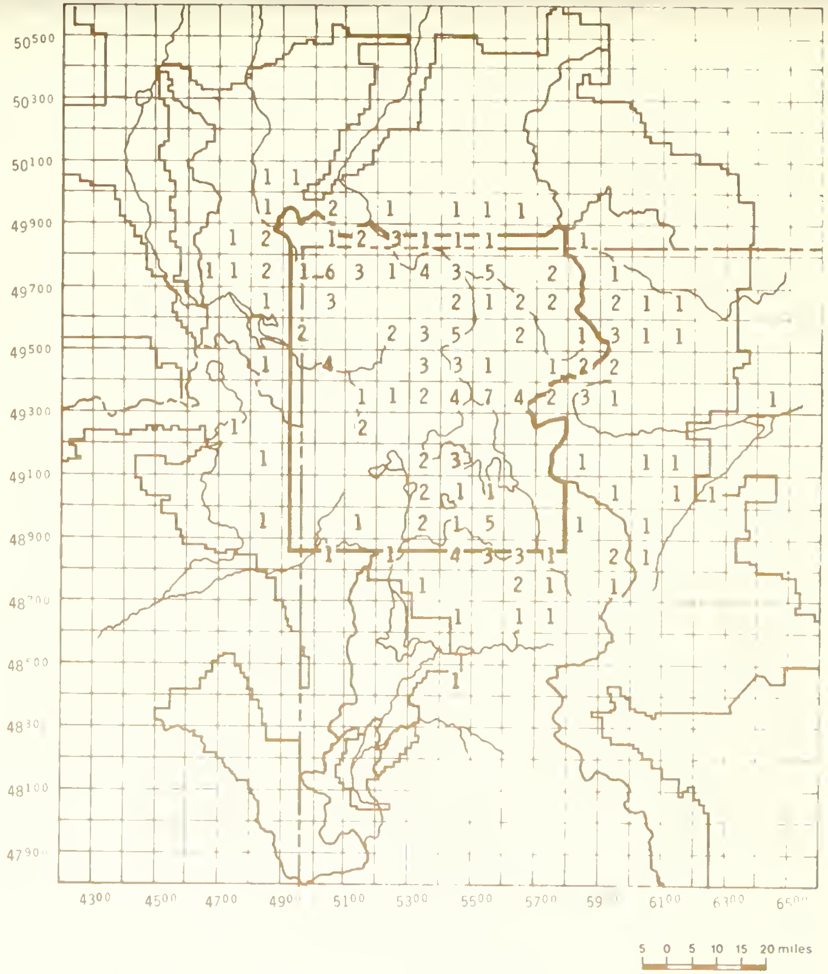

Figure 13.—Numbers of years in the 1973 through 1979 period that verified sightings of female grizzly bears with young were reported

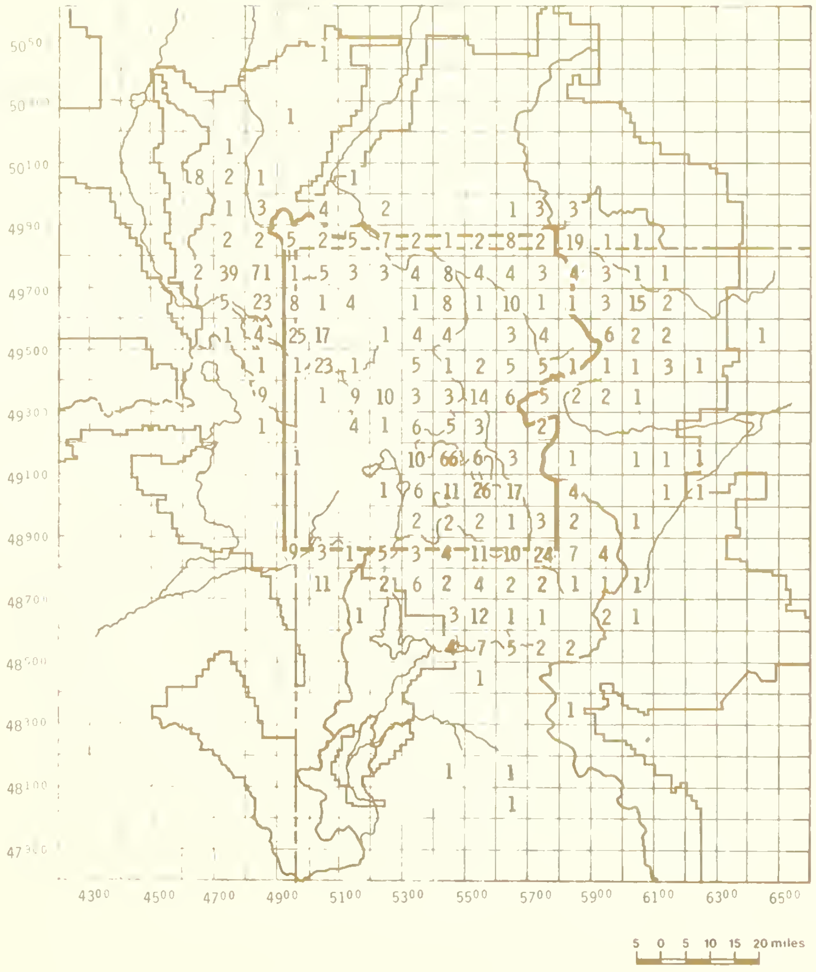

Figure 14.—Composite of verified observations of grizzly bear sign, 1973 through 1979.

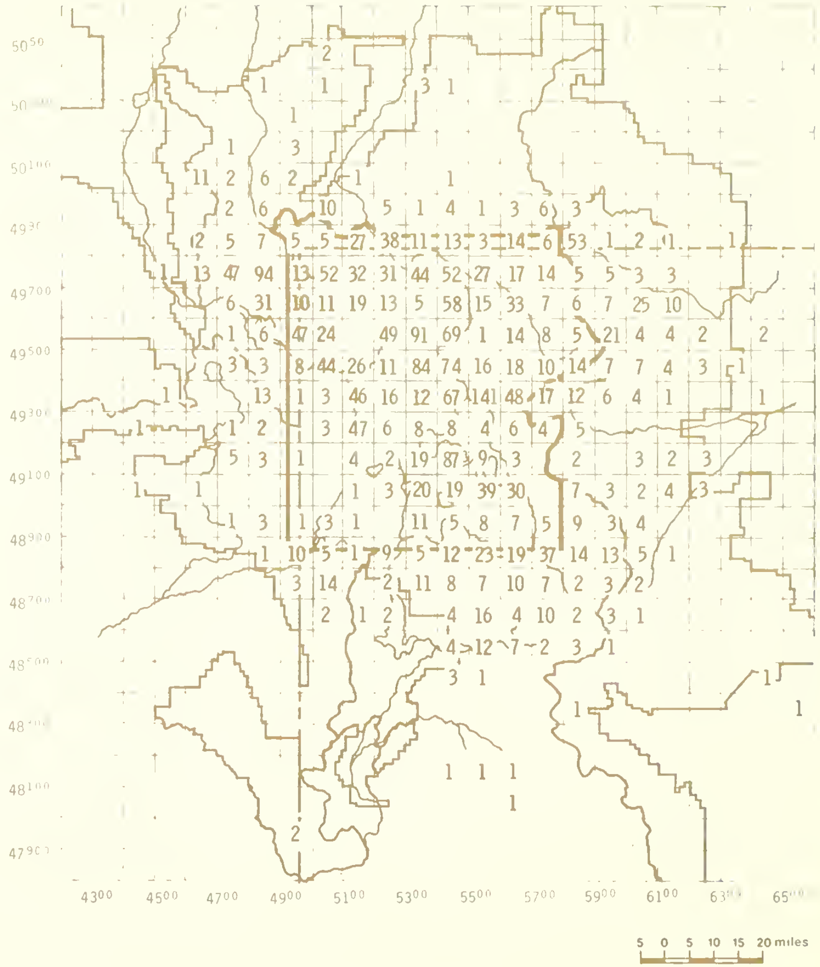

Figure 15.—Composite of all grizzly bear sightings and sign, verified and unverified, for years 1973 through 1979.

Other factors must be considered when interpreting results:

Observability of bears. When weather conditions in timber stands promote a luxuriant growth of herbaceous understory that retains its succulence well into summer, bears apparently find abundant forage without leaving protective cover (Knight and others 1976). Bears are less readily observed then than in drier years when bears are forced to forage more in open areas.

Observer attitudes. As Roop (1980) indicated, "The sociological and political climate of grizzly bear management can strongly influence the number of bear sightings reported by independent or nonagency forest users." Thus, any real or suspected change in bear management policy influences the willingness of individuals to report grizzly bear sightings according to how that information eventually may be used to their advantage or disadvantage.

Human use. Observations are only possible where people and bear use overlap, so areas of comparatively high or low bear observations must be evaluated with this in mind.

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Research Note
INT-322

October 1982

Thinning and Pruning Western White Pine: A Potential for Reducing Mortality Due to Blister Rust

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ABSTRACT

*Thinning and pruning were tested as potential methods for reducing mortality of western white pine (*Pinus monticola*) infected by the blister rust disease caused by* Cronartium ribicola. *Five years after treatment thinning had increased the number of new lethal infections per tree. Pruning counteracted the effects of thinning.*

KEYWORDS: *Pinus monticola, Cronartium ribicola,* pruning, thinning, disease control

INTRODUCTION

Cronartium ribicola Fischer ex. Rabenh., the cause of blister rust disease in white pines, has created a serious mortality problem in many areas of North America where native white pines are the most productive timber species. Direct control methods, such as chemical treatments or eradicating *Ribes* spp., the alternate host, appear to be ineffective and/or uneconomical in the West; so in 1968, management of western white pine on National Forests in the Northern Region was temporarily suspended (Ketcham and others 1968).

During the late 1960's, a breeding program begun by the Forest Service in 1950 was yielding favorable results. Effective resistance and a large number of resistance mechanisms were indicated by Bingham and others (1971). Other management strategies to reduce rust-caused losses were also evaluated to provide alternatives and to integrate these with resistant stock (McDonald 1979).

Cultural operations, such as thinning and pruning, are among those alternatives. Although these are commonly used silvicultural practices in the western white pine region, their effectiveness in rust-hazard reduction has not been demonstrated. Stillinger (1947) reported on one pruning study on the Clearwater National Forest. The results were premature and the study inconclusive. Studies on eastern white pine (*Pinus strobus* L.) (Stewart 1957; Stewart and Ritter 1962; Weber 1964) and sugar pine (*Pinus lambertiana* Dougl.) (Hayes and Stein 1957) indicated that pruning was effective for reducing losses due to blister rust. No data have been published on the influence of thinning on blister rust development.

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A considerable body of knowledge exists about the basic biology of blister rust and its expression under natural conditions. Stillinger's (1947) data and observations from our studies (unpublished data)[4] indicate that nearly 75 percent of the "lethal" infections (those expected to eventually kill at tree) occur in the lower one-third of a tree. These data represent samples from a wide range of sites and tree ages to 60 years of age.

Spore dispersal in relation to air currents has been studied minimally in western white pine stands (Lloyd 1959). VanArsdel (1961) documented spore dispersal patterns and subsequent infection patterns with eastern white pine in the Lake States. These studies suggested that the microenvironments suitable for infection are more favorable near the ground. Stillinger's (1947) data and our observations (unpublished data)[5] do not reveal changes in height distribution of infections associated with high infection years.

Tree growth rate does not appear to influence growth of branch infections toward the bole, but does seem to influence the proportion of cankers that are lethal (unpublished data).[6] Faster growing trees have fewer lethal infections (infections that will eventually kill the tree). White pine, such as open grown trees, with faster growth exhibit growth segments of greater length than trees in dense stands (unpublished data).[7] On the average, these branch segments are incapable of supporting continuous canker growth; so a greater proportion of the infections are nonlethal. Criteria for judging lethality by length and diameter of branch segments are described by Hungerford (1977).

Our objectives in the study described here, initiated in 1969, were to test the hypothesis that pruning and/or thinning of white pine crop trees will reduce the mortality from blister rust. Pruning was expected to eliminate the hazard of existing infections and reduce target area and therefore the probability of new lethal infections. Thinning was expected to increase branch growth and therefore reduce the probability of new infections being lethal. Increased spacing was expected to decrease the target area exposed to favorable conditions for infections.

We will describe the study sites and treatments, then present the preliminary results. These results are based upon examination and analysis of infection intensity 5 years following treatment. While not conclusive, because sufficient time has not elapsed for mortality to occur, the results are indicative of the final outcome.

[4]Study 116, Forest Pathology Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[5]Study 91, Forest Pathology Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[6]Study 91, Forest Pathology Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

[7]Study 510, Silviculture Research Work Unit, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

TEST SITES AND TREATMENTS

Five northern Idaho white pine stands between 10 and 20 years of age and at least 20 acres in size were selected for this study. General location of each study area is shown in figure 1. Selected stands were ecologically classified as being of the *Tsuga heterophylla-Pachistima myrsinites* or *Thuja plicata-Pachistima myrsinites* habitat types (Daubenmire and Daubenmire 1968). In most stands, *Pinus monticola* Dougl. was the dominant conifer species, with lesser amounts of *Abies grandis* Dougl. Lindl. (grand fir), *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir), *Tsuga heterophylla* (Raf.) Sarg. (western hemlock), *Picea engelmannii* Parry ex Engelm. (Engelmann spruce), *Larix occidentalis* Nutt. (western larch), and *Thuja plicata* Donn (western redcedar) being present. Individual trees averaged 1.0 to 2.8 inches (2.5 to 7.1 cm) d.b.h. and 7 to 17 ft (2.1 to 5.2 m) in height. Stocking density varied from 2,000 to 13,000 stems per acre.

In each test area, nine square 1-acre (0.4 ha) plots (three replications of each treatment) were laid out and thinned to a 10- by 10-ft (3- by 3-m) spacing. The remainder of the stand was thinned to a 14- by 14-ft (4.3- by 4.3-m) spacing. In each test area, the nine treated plots and controls were located so they could be divided into three groups based on relative slope position—lower, middle, or upper. Treatments were assigned randomly to plots within a slope group. Three treatments were tested: (1) thinning, (2) thinning plus pruning all crop trees, and (3) thinning plus pruning only the western white pine crop trees. All crop trees were selected by using Northern Region guidelines, except that white pines were not discriminated against unless they had bole infections or had branch infections within 4 inches of the bole (termed "nonprunable" trees). Pruning treatments were superimposed onto the thinning treatments. Pruning consisted of removing both live and dead branches from the lower one-third of the tree height and removal of all obviously infected branches that could be reached in the remaining crown. Branches were pruned flush with the bole with handtools or small chain saws. Control plots were located on adjacent unthinned portions of the stand, and crop trees were selected as they were on thinned plots. Neither thinning nor pruning was conducted in the control plots.

Within each plot, a central 1/4-acre (0.1-ha) area was established as the sample area for tree measurements. Immediately prior to treatment, we measured diameters at 4.5 ft (1.3 m), tree heights, and live crown lengths (that portion of the main stem with live branches) for all trees within the quarter acres. The white pines were examined for rust infections. Each infection was identified by its age and its location on the tree, and each was judged as to its lethal or nonlethal potential (Hungerford 1977). This report examines the data collected before treatment and 5 years following the treatments.

Data were subjected to analysis of variance, with observations adjusted for total and lethal canker

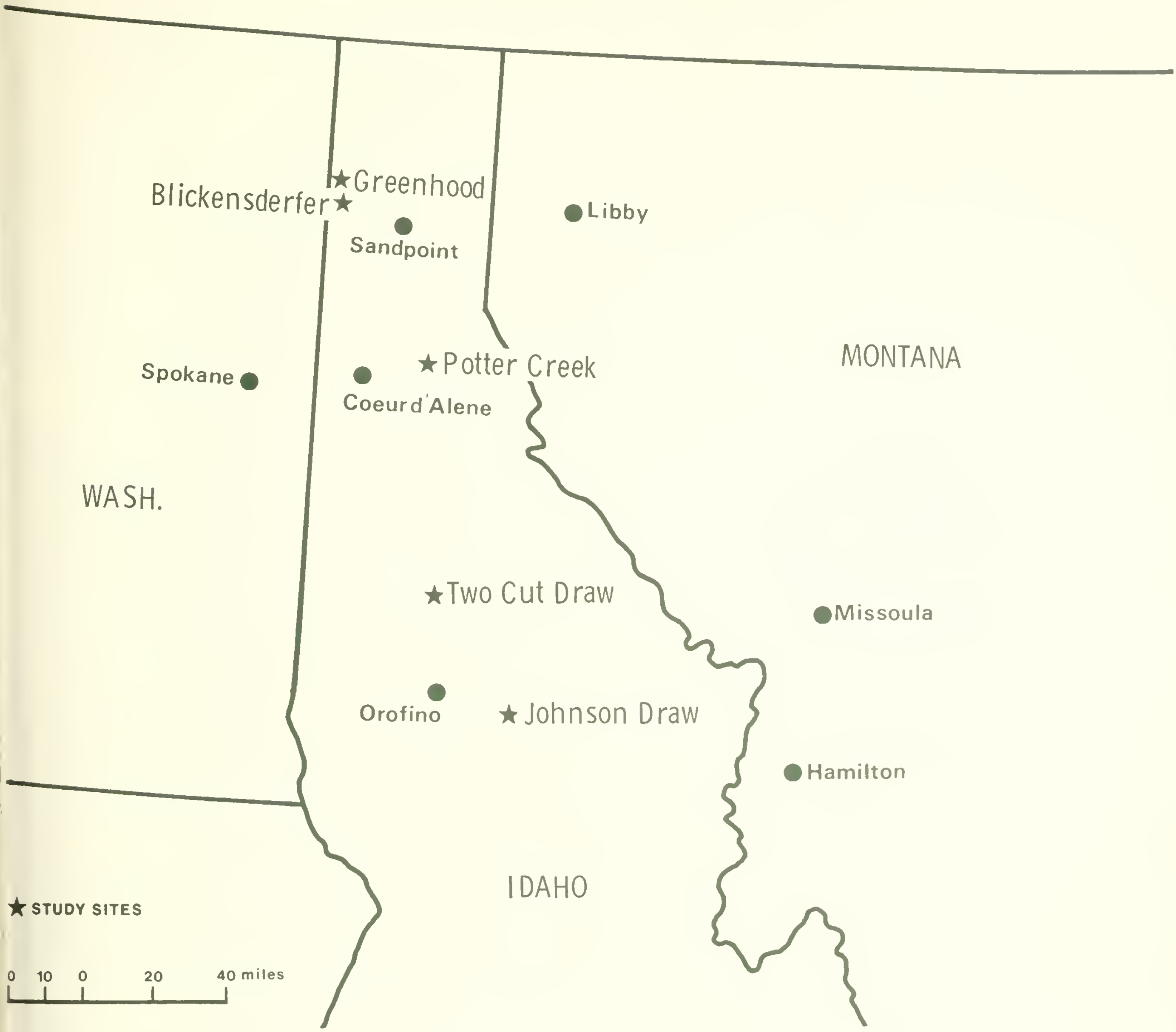

Figure 1.—Location of study sites within the Inland Empire sites are marked with a star.

numbers, tree diameter, and tree height before treatment. Additionally, data were transformed ($Y_i = \ln (X_i + 0.5)$, where X_i is the number of infections on the ith tree) to minimize the dependence in data on the variance and mean from a sample. Each study area was considered as a separate analysis because variances among areas were not homogeneous. Tests were for a significance level of $P \leq 0.05$.

RESULTS

Except for the Greenhood area, slope position did not affect infection rate. In all areas the thinned-only treatment resulted in significantly greater numbers of new lethal infections per tree than in the pruning treatments (table 1). The number of new lethal infections per tree were similar for both of the pruning treatments and the controls. Except for Potter Creek and Two Cut Draw, significantly more new lethal infections were found in the thinned-only treatments than in the controls. Except in Johnson Draw, numbers of lethal infections per tree on the pruned treatments were low. For both pruned treatments 66 to 100 percent of the infections were lethal, while for thinned-only and control plots (with the exception of Potter Creek) 30 to 60 percent of the infections were lethal.

It is important to note that treatment effects on new lethal infections are similar over test areas with either high (Johnson Draw) or low (Potter Creek) numbers of infections. Thinning increases the number of new lethal infections per tree over the other two treatments relative to infection level for the site. Pruning resulted in infection rates 50 to 80 percent less than thinning only, but not different from the controls. Another indicator of treatment effectiveness is how many trees are free of infections. We found that fewer trees on the thinned-only treatments were free of lethal infections than on either of the other treatments after 5 years (table 2). Pruned and thinned plots had nearly as many or more trees free of lethal infections than the control plots after 5 years. In addition, more trees on the pruned plots could be effectively pruned again to remove new lethal infections than on either of the other treatments.

When all infections are considered in the analysis (lethal and nonlethal branch infections), we found the pruned treatment had significantly fewer new infections than either of the other treatments (table 3). With this expanded number of infections, the thinning treatment was not significantly different from the controls. As with the lethal infections, the pruned treatments had more trees free of infections than either of the other treatments (table 2).

Table 1.—Average numbers of new lethal infections per tree by treatment for each area 5 years after treatment. Treatments with different lower case letters are significantly different at P = ≤ 0.05. Statistical tests were performed on adjusted, transformed values

Area	Numbers of lethal infections prior to treatment[1]	New lethal infections since treatment[1] — Treatment: White pine pruned	All pruned	Thinned only	No treatment
Johnson Draw	0.9	6.9(a)	5.8(a)	10.9(b)	5.0(a)
Greenhood	.2	1.6(a)	3.2(b)	6.0(c)	1.7(a)
Blickensderfer	.2	1.2(a)	1.0(a)	2.7(b)	1.1(a)
Two Cut Draw	1.0	1.5(a)	1.6(a)	3.6(b)	1.6(a,b)
Potter Creek	.4	.5(a)	.4(a)	1.5(b)	1.2(b)

[1]Average per tree.

Table 2.—Percent of trees by treatment and area with no new infections and no lethal infections before treatment period (1969) and after 5 years (1974). The percent of trees with lethal cankers not prunable is also shown, along with the number that died after 5 years

	Trees with no lethal infections						Trees with no infections						Trees not prunable			Ru kil
	1969			1974			1969			1974			1974			
Area	P[1]	T[1]	C[1]	P	T	C	P	T	C	P	T	C	P	T	C	
	Percent															N
Johnson Draw	49	54	51	14	10	19	26	24	38	12	6	10	44	57	55	
Greenhood	88	87	86	34	11	35	73	73	77	28	9	29	28	50	52	
Blickensderfer	88	94	91	53	24	36	78	88	87	53	12	16	21	55	40	
Two Cut Draw	50	48	65	38	24	41	33	29	45	33	13	23	22	51	33	
Potter Creek	73	77	73	72	46	50	67	72	66	72	43	44	19	36	41	

[1]P = pruned plots;
T = thinned only plots; and
C = plots having no treatment.

Table 3.—Average numbers of new infections per tree by treatment for each area 5 years after treatment. Treatments with different lower case letters are significantly different at P = ≤ 0.05. Statistical tests were performed on adjusted, transformed values

Area	Numbers of infections prior to treatment[1]	New infections since treatment[1]			
		Treatment			
		White pine pruned	All pruned	Thinned only	No treatment
Johnson Draw	3.6	8.4(a)	6.8(a)	19.3(b)	13.5(b)
Greenhood	.7	2.4(a)	3.4(a)	9.8(b)	3.6(a,b)
Blickensderfer	.3	1.3(a)	1.0(a)	6.2(b)	3.6(b)
Two Cut Draw	2.4	1.7(a)	2.2(a)	6.2(b)	3.2(b)
Potter Creek	.6	.5(a)	.4(a)	1.6(b)	1.7(b)

[1]Average per tree.

DISCUSSION

Thinning a western white pine stand without emoving blister rust-infected branches will increase nfection frequency and decrease the likelihood of mainaining western white pine as a stand component. Based on the results of thinning these stands in five reas of northern Idaho, we reject the hypothesis that hinning will reduce blister rust hazard to western vhite pine. It is apparent that microenvironments suitble for infection were not altered. Lethal infections vere not reduced, at least during this period, because of hinning-induced tree growth. We cannot explain onclusively the cause of this increase in new lethal nfections in response to thinning. It appears likely, owever, that more foliage was exposed to spore loads n the thinning treatment. We would expect the umber of infections to increase as target area ncreases. Calculations of target area (based on stand ensities, tree size, and thinning specifications) indicate hat we increased target area by 100 percent on the hinning treatments. Based on this increase, we would xpect to have 100 percent more new lethal infections han on the controls. With the exception of Potter reek, we observed more than 100 percent increase for ll areas (table 1). Opening the stand by thinning may ncrease branch survival by reducing suppression. This lso should increase numbers of new lethal infections.

Pruning of thinned trees of all species or only western hite pine crop trees negated the increased numbers of nfections per tree resulting from thinning only and, in nost cases, resulted in fewer infections than in conols. Based on these results we conditionally accept the ypothesis that pruning reduces rust hazard and subequent mortality. Where pruning was done on thining treatments, the data support the hypothesis. runed and thinned treatments, however, were not ifferent from untreated areas. Unfortunately, we did ot prune trees in unthinned situations which makes it ifficult to interpret pruning alone. Pruning in addition thinning did successfully remove existing infections, educing probability of mortality. Calculations of target rea indicate that pruning reduced target area by 55 ercent or more. The data (table 1) show that pruning reduced the number of new lethal infections by from 41 to 67 percent. If pruning alone had been done (no thinning) on our test sites, the exposed surface area would not have been reduced much below the controls. Pruning would only have removed the target area already screened by other branches. According to these projections, the target area and number of new infections would have been the same as for the thinned and pruned treatments.

The period following treatment included at least one extremely favorable year for rust infection. In 1969, the average annual percentage of trees infected over the life of the stands was about 2.9 percent, nearly the same as that reported by Carlson and Toko (1968). During the period 1969 to 1974 this rate increased to nearly 8 percent on the thinned-only and control plots, and increased to 3.4 percent on the pruned areas. While the general infection level was higher in 1974, distribution of lethal infections does not appear to have changed.

Treatment effects were similar on all areas with a similar percent increase or decrease in infection noted. It is questionable, however, that pruning in areas of high infection levels can be effective. Even though the hazard will be reduced on high hazard areas, the probability of saving trees is still remote. Evaluation of these treatments after an additional 5 years will give a much better idea of effectiveness in this regard.

Even though slope effects were not generally significant in our study, a large variation in infection intensity exists between the study sites. This suggests that infection rate does vary widely but our plot layout was not adequate to detect slope effects. Results from Greenhood, where slope position did impact infection, indicated a significant increase in infection at the lower slope. Basins and lower slopes may be high hazard sites.

The variation in infection intensity shown here supports McDonald's (1979) suggestion of differential infection intensities with varying sites. McDonald suggests that the development of a method to assess potential for infection, that is, a hazard rating system, would allow for the propagation of low level resistant white pine on large areas of land with low infection hazard. We also believe that the use of a hazard rating system would allow for maximum efficiency in applying thinning and pruning for control. Thinning and pruning could be applied to low and perhaps moderate hazard areas, but would not be effective in high hazard areas. It appears that the development of a hazard rating system for blister rust infection will be a key to management of blister rust on western white pine.

SILVICULTURAL AND ECONOMIC ASPECTS

Where disease is not a consideration, thinning in 50-year-old white pine stands increases diameter growth, but not height growth (Foiles 1956b). Volume production and diameter growth are maximized for 20-year-old stands at a 10 by 10 spacing (Marvin W. Foiles, personal communication). Pruning up to one-third of the live crown may slightly depress diameter growth for a short period (Helmers 1946). Thinning in conjunction with pruning, however, offsets any depressing effect (Smith 1954). Pruning improves lumber grade (Fedkiw and others 1960; Horton 1966) by producing high quality knot-free lumber (Funk 1961; Henman 1963). Several reports (Fedkiw and others 1960; Shaw and Staebler 1950, 1952; Huey 1950) indicate that pruning can be a good investment. Since clear timber will stay in demand, the financial picture should remain favorable. Several studies report the results of pruning methods, times, and costs (Lemmien and Rudolph 1963; Horton 1966; Foiles 1956a).

RECOMMENDATIONS

At this time, we do not recommend general thinning in white pine stands of the Northern Region. Rather, until a hazard rating system is developed and we have further evaluated treatment effects, we suggest that timber stand improvement efforts with western white pine be confined to stands with obviously low infection levels. Additionally, we suggest that where thinning is to be done, white pine crop trees with the fewest infections (and more importantly, without lethal nonprunable infections) have the lower third of the crown pruned. This will take advantage of naturally produced resistance (Hoff and others 1976) and reduce potential mortality. In addition, economic benefits resulting from producing higher quality lumber can be realized.

Thinning and pruning should be accomplished as late in the development of the stand as possible to allow for maximum selection pressure on white pine while allowing for maximum growth acceleration. This will vary by areas, but approximately 25 to 30 years of age would be best.

Utilization of these techniques will take advantage of reduced infection pressure and low levels of resistance while maintaining maximum adaptability (diversity) in the host population (Hoff and others 1976; McDonald 1979).

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Canada
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Spruce Budworms
Program

United States Department of Agriculture
Forest Service
Intermountain Forest and Range Experiment Station
Research Note INT-323
December 1982

Recovering Western Spruce Budworm Larvae from Sticky Traps Covered with Volcanic Ash[1]

Leon J. Theroux
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ABSTRACT

Ash fallout from the May 18, 1980, eruption of Mount St. Helens in the State of Washington covered more than 460 sticky traps in western Montana forests. The traps were deployed to study dispersal of western spruce budworm larvae. A technique is decribed for removing the ash from the sticky trap surface and extracting and counting the larvae.

KEYWORDS: *Choristoneura occidentalis* Freeman, western spruce budworm, volcanic ash, larval dispersal, Mount St. Helens, trapping insects

INTRODUCTION

As part of current studies to measure (1) loss of Stage II western spruce budworm *(Choristoneura occidentalis* Freeman) larvae during dispersal, and (2) the relationship of dispersing larvae to the incidence of tree seedling establishment and development, we install traps to catch larvae in the forest before the onset of the spring dispersal period. At the end of the 8- to 10-week dispersal period, we collect the traps and return them to the laboratory for examination.

Our traps (fig.1) consist of a 24- by 18-inch (61-by 46-cm) piece of 3/8-inch (9.4-mm) plywood, covered with butcher paper, which is coated with a sticky substance (TACK TRAP[3]) that captures dispersing

[1]Work leading to this publication was wholly funded by a USDA Forest Service-sponsored program entitled, "Canada-United States Spruce Budworms Program."

[2]Biological technician and supervisory research entomologist, respectively, located at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mt.

[3]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclu ion of others that may be suitable.

Approved for publication by Intermountain Station September 1981

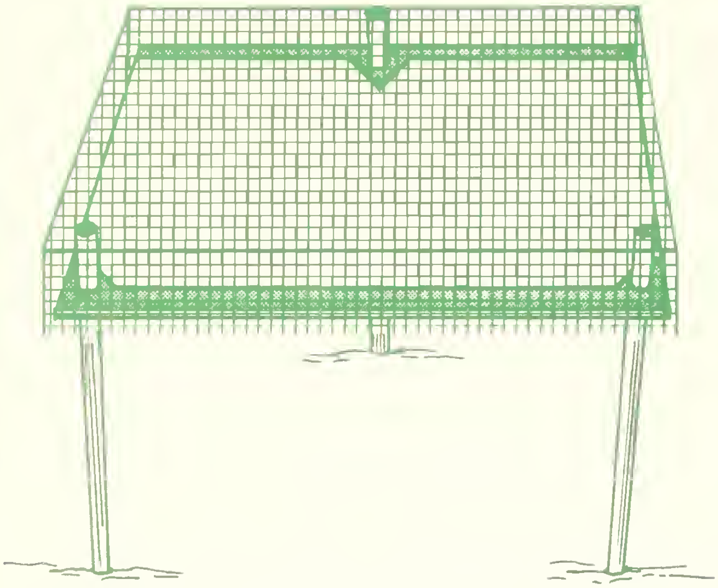

Figure 1.—Dispersal trap supported by three plastic stakes and covered with hardware cloth screen.

budworm larvae. The traps are supported 18 inches (46 cm) above the ground by three stakes and covered with a piece of 1/2-inch (1.25-cm) mesh hardware cloth to prevent birds and small mammals from sticking to the trap.

During late April 1980, we installed 467 of these traps at eight study areas in western Montana to study spring dispersal patterns of western spruce budworm larvae. These eight study areas are within a 70-mile (113-km) radius of Missoula, Mt.

On May 18, 1980, Mount St. Helens erupted, and over a 4-day period, from May 18 to 21, volcanic ash was deposited at varying depths within the fallout zone (National Geographic 1981). All of our eight study areas in western Montana were in a zone where ash accumulated to depths of from 0.062 to 1 inch (1.6 to 25.4 mm) (fig. 2). Presumably, that amount of ash also accumulated on our traps, scattered throughout the eight study areas. At the time of the ash fall, western spruce budworm larvae had been dispersing for approximately 4 weeks, and the dispersal period was peaking or had peaked at most of our study areas. (We determine

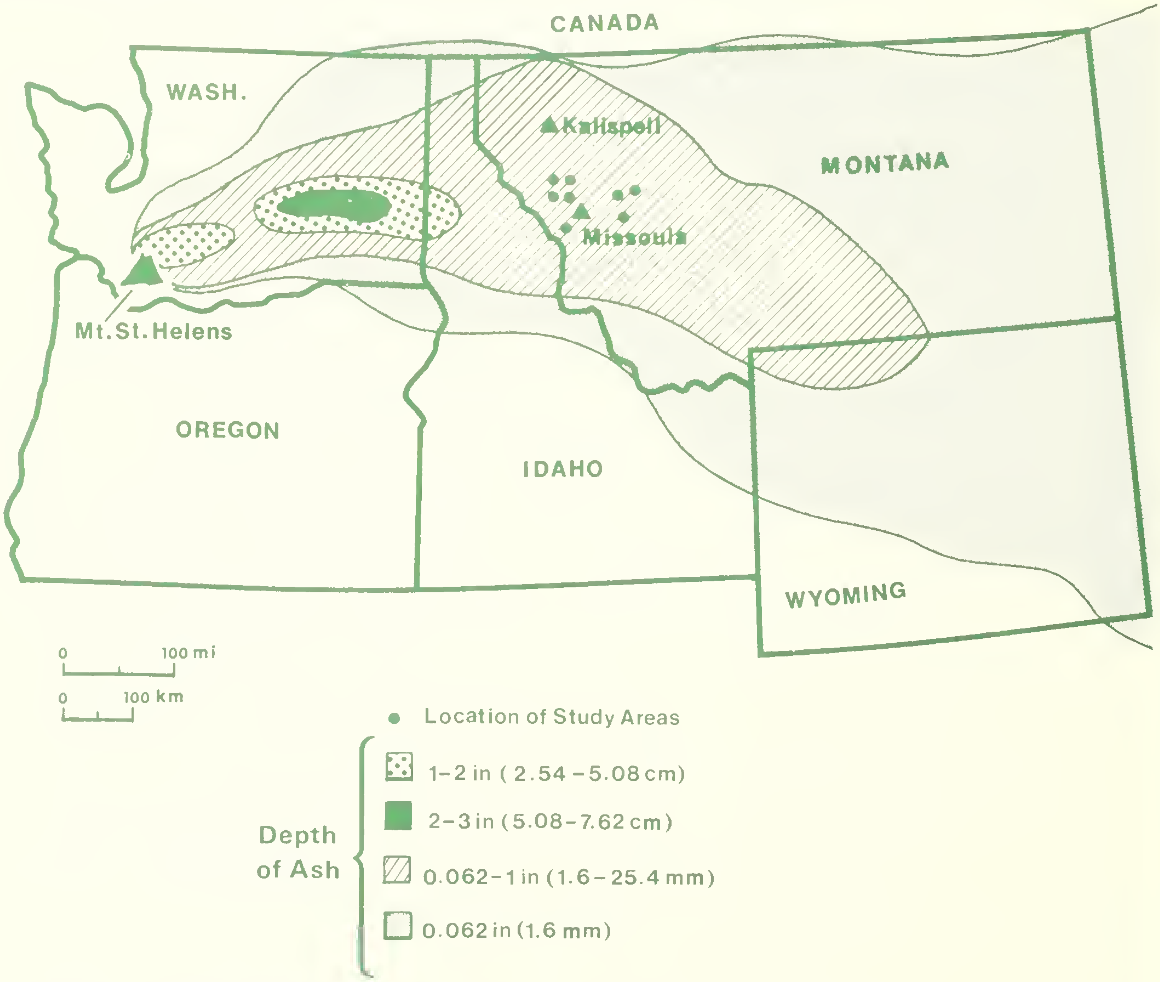

Figure 2.—The generalized pattern of ash fallout in the Pacific Northwest states from the 18 May 1980 eruption of Mount St. Helens (adapted from Moen and McLucas 1981), showing relative locations of eight areas where western spruce budworm larval dispersal studies were in progress during the ash fall.

the larval dispersal period each spring by weekly monitor trapping at four study sites.) Ash deposited on the sticky surface of the traps rendered them ineffective in capturing larvae throughout the remainder of the dispersal period.

After the ash fall abated, rain began falling in western Montana. In the 4-day period between May 22 and 26, 3.7 inches (9.4 cm) of rain fell in Missoula, Mt. (National Climatic Center 1980). Rainfall on May 22 and 23 alone, 1.69 inches (4.3 cm), equaled nearly 10 percent of Missoula's average annual precipitation (Potts 1980). We are not certain how much rain fell at our eight study areas. Because the heavy rains were general and widespread, however, and because most of our study areas are higher in elevation than Missoula, we presume that as much or more rain fell at our study areas as was measured at the National Weather Service station in Missoula.

In early June we collected the dispersal traps and returned them to the laboratory for examination. Our normal lab procedure consists of cutting the sticky paper into six equal rectangular 6- by 12-inch (15- by 30-cm) pieces, examining the pieces under a binocular microscope, and recording the number of larvae on each section. Although the rain may have washed some ash from the traps, or compacted the ash on the traps (Cook and others 1981), 1 to 2 mm of ash was retained on the sticky surface of the traps, making it impossible to see through the ash and visually examine and count budworm larvae in the usual manner. It was apparent that we needed a new trap examination procedure to determine the incidence of larval dispersal, at least up to the date of the ash fall.

METHODS

The manufacturer[4] of TACK TRAP recommends using a light petroleum solvent (paint thinner) to clean TACK TRAP from hands and tools. Based on this recommendation, and after a series of attempts at partially washing the traps in solvent to remove the ash, we developed the following procedure (fig. 3) to remove the ash, debris, and TACK TRAP from the traps, and to recover and count the western spruce budworm larvae.

1. The sticky-coated paper was cut in six 6- by 12-inch (15- by 30-cm) pieces to facilitate handling.
2. Each piece was dipped into a wide-mouthed 6-qt (5.7-liter) jar containing approximately 1 gal. (3.785 liters) of solvent, and gently agitated by hand in a vertical dipping motion until all of the TACK TRAP had dissolved and the ash, larvae, and debris had washed off.[5]
3. The contents of the container were passed through two 60- by 40- mesh brass screens. The screen openings measured 0.48 by 0.31 mm. The ash particles, which ranged in size from <0.1 to 80 microns,[6] passed through both screens. Most debris and Stage II western spruce budworm larvae, with an average body length and head capsule width of approximately 1.38 mm and 0.31 mm, respectively, were retained on the screen.

This two-screen filtering system assured that any larvae that might pass through the first screen would be recovered on the second screen. Early in the development of this procedure, we examined both the screens and the precipitate after the solution had been poured through the screens. We found that few larvae were being washed through the first screen onto the second, and that no larvae passed through the second screen.

After all six sections of a trap had been washed and the solution filtered, the filtrate was set aside for approximately 1/2 hour while the suspended ash settled out. The solvent was then decanted and reused. By recycling the solvent, we could process 10 to 12 traps before the solvent became too contaminated with fine ash and TACK TRAP residue and had to be discarded.

4. After an entire trap was processed, we removed the screens from the funnels, turned the screens upside down, and then, separately, backwashed them with a wash bottle containing solvent into one or more labeled petri dishes.
5. The screens and the material washed into the petri dishes were examined under a dissecting microscope, and all Stage II budworm larvae in the dishes and remaining on the screens were counted.
6. The number of larvae per trap were recorded on an appropriate data form.

DISCUSSION

The Mount St. Helens eruption created some real problems with our western spruce budworm larval dispersal studies. Nevertheless, the methods we have described for removing ash and larvae from our traps enabled us to salvage research data that appeared to be hopelessly lost, and allowed us to maintain the continuity of our studies.

Because the ash fell at the peak of larval dispersal, the larval counts from the traps do not reflect the incidence of larvae dispersing after the ash fall. From our weekly monitor trapping, which continued throughout the spring dispersal period, we know the percentage of the overwintering larvae that dispersed after the ash fall. We have adjusted the counts of larvae from the ash-covered traps by that amount.

The cost of the procedures we describe here was $2.84 per trap, compared with $2.64 per trap for our normal laboratory procedure for microscopically examining the

[4]Animal Repellents, Inc., Box 999, Griffin, GA 30224.

[5]The sticky-coated paper was washed in a well-ventilated area where smoking and open flames were prohibited, and other containers of solvent were properly sealed and stored.

[6]Personal communication with J. Moore, geologist, University of Montana, Missoula.

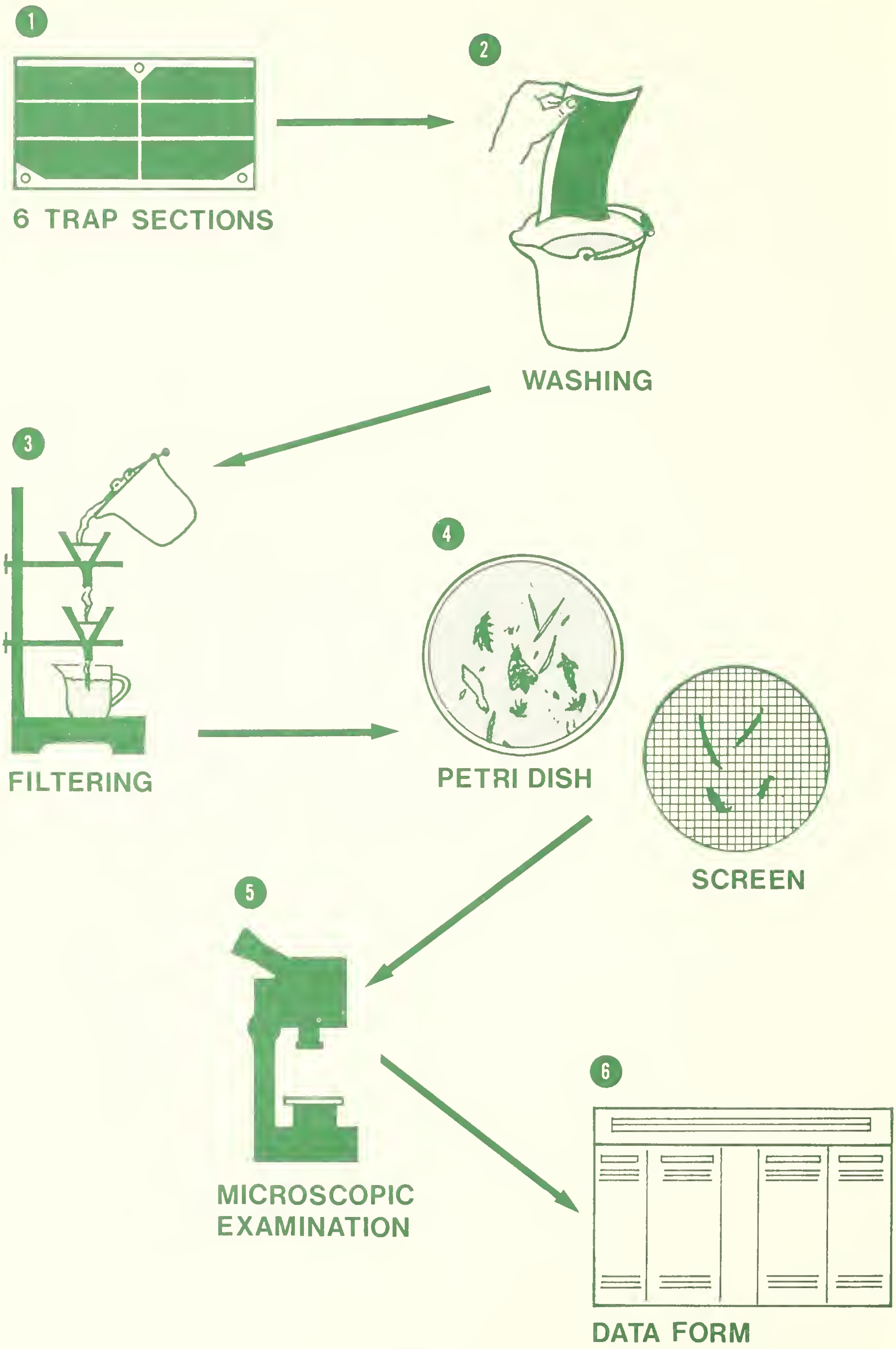

Figure 3.—Sequence for removing volcanic ash from sticky traps and recovering and counting western spruce budworm larvae.

dispersal traps. The $0.20-per-trap difference was for materials needed for the washing procedure. This is an insignificant difference when compared to the value of the research data which otherwise would have been lost.

We plan to continue using the washing procedure because it is useful on traps not covered with ash. The process will be used on traps where the sticky surface is covered with abnormal amounts of dust, debris, or other insects (particularly flies). Under these circumstances, many of the tiny Stage II larvae are hidden from the examiner's view and are not counted.

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INT-324

January 1983

Inventory of Salmon, Steelhead Trout, and Bull Trout: South Fork Salmon River, Idaho

**William S. Platts
and
Fred E. Partridge[1]**

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ABSTRACT

Aquatic habitats and respective fish populations were studied in the South Fork Salmon River during the summer of 1977. From the Warm Lake Bridge to the headwaters the channel consisted of 74 percent riffle and 26 percent pool, with surface substrate of 21 percent boulder, 40 percent rubble, 24 percent gravel, and 15 percent fine sediment. Below the Warm Lake Bridge to the confluence of the Secesh River the channel consisted of 55 percent riffle and 45 percent pool, with surface substrate of 32 percent boulder, 35 percent rubble, 16 percent gravel, and 17 percent fine sediment. Juvenile chinook salmon and rainbow-steelhead trout were found throughout the river, except in the upper 5 miles (8 km), where only bull trout were found. The river reach in the Stolle Meadows contained the highest densities of fish, with juvenile chinook salmon and sculpin the most numerous fish present. Chinook salmon and rainbow-steelhead trout densities were lower than reported in most other Idaho streams having anadromous fishes. Of the habitat attributes measured, only stream width showed any correlation with fish populations. As stream width increased in the river reach above the Warm Lake Bridge, bull trout numbers decreased.

KEYWORDS: fish, bull trout, anadromous, sediments, aquatic habitat, standing crop

INTRODUCTION

Adult summer chinook salmon (*Oncorhynchus tshawytscha* [Walbaum]) and steelhead trout (*Salmo gairdneri* Richardson) returning from the ocean to the South Fork Salmon River (SFSR) to spawn have steadily declined in numbers since 1957. This decline resulted in a sport fishing closure on both species and caused their present consideration for classification as a "threatened or endangered" species in the Salmon River drainage. There is no evidence that populations have stabilized or that the downward population trend will not continue. Decline of salmon populations in the Salmon River drainage has been caused mainly by impoundments (upstream-downstream passage problems) in the lower Snake and Columbia Rivers. Fish populations in the SFSR have also been adversely affected by past deposition of large amounts of sediments.

Idaho Department of Fish and Game monitors adult summer chinook salmon runs into the SFSR by annual redd counts. Knowledge of success in rearing juvenile chinook salmon and steelhead in the SFSR drainage has been limited to studies conducted in the tributaries (Platts and Partridge 1978). Little information is available concerning rearing success in the main river. This report evaluates the aquatic habitat, fish densities, and fish growth in the SFSR and discusses the river rearing areas used by juvenile chinook salmon and rainbow-steelhead trout.

[1]Research fishery biologists, located at the Intermountain Station's Forestry Sciences Laboratory, Boise, Idaho, and Idaho Department of Fish and Game, Bonners Ferry, Idaho, respectively.

STUDY AREA

The 80-mile-long (130 km) SFSR is a major tributary of the Salmon River and drains a 1,270-mi^2 (3 290-km^2) watershed representative of much of the forested mountainous terrain found in central Idaho. The study area covers the upper 45 mi (72 km) of the river. Channel elevations of the study sites range from 6,850 ft (2 090 m) in the headwaters to 3,620 ft (1 100 m) at the confluence of the Secesh River. The river is low in mineral content (total dissolved solids about 60 to 100 mg/liter) because of the dominant granitic bedrock in the watershed. The river's tributary waters average only 60 mg/liter total dissolved solids (Platts 1974).

The SFSR historically contained Idaho's largest chinook salmon run,which is composed entirely of summer chinook salmon. This race has been reduced from 10,000 returning adults in the mid–1950's (personal communication with Howard Metsker, U.S. Dep. Interior, Fish and Wildlife Serv.) to about 300 returning adults in 1980. Most of the SFSR chinook salmon spawn in the river, with a few spawning in tributary streams. Juvenile chinook salmon rear in the SFSR and in the lower portions of the main tributaries (Platts and Partridge 1978).

Fish populations in the SFSR are composed of chinook salmon, rainbow-steelhead trout, bull trout (*Salvelinus confluentus* [Suckley]), brook trout (*Salvelinus fontinalis* [Mitchill]), cutthroat trout (*Salmo clarki* Richardson), mountain whitefish (*Prosopium williamsoni* [Girard]), sculpin (*Cottus* spp.), dace (*Rhinichthys* spp.), sucker (*Catostomus* spp.), and Pacific lamprey (*Entosphenus tridentatus* [Gairdner]).

Study Sites

Randomly selected study sites used since 1967 (Platts 1972; Megahan and others 1980) to monitor stream channel substrate changes over time in the SFSR were used in this study (fig. 1). The 48 study sites averaged about a mile (1.6 km) apart, starting at the headwaters and ending at the confluence with the Secesh River. Five grouped transects crossing the river at 50-ft (15-m) intervals comprised one study site. Aquatic structural data were collected along each of the 240 transects. Corresponding fishery data were collected from the entire 200-ft (61-m) site at each of the even-numbered sites.

The Warm Lake-Cascade Bridge was used to divide the study area into two reaches. The river reach downstream from the bridge to the confluence of the Secesh River is referred to as the downstream reach and the river above the bridge as the upstream reach. Eight fish study sites in the 14 mi (22 km) of river in the upstream reach were sampled for fish by electrofishing; the 16 sites in the 31 mi (50 km) of downstream reach were sampled by snorkeling.

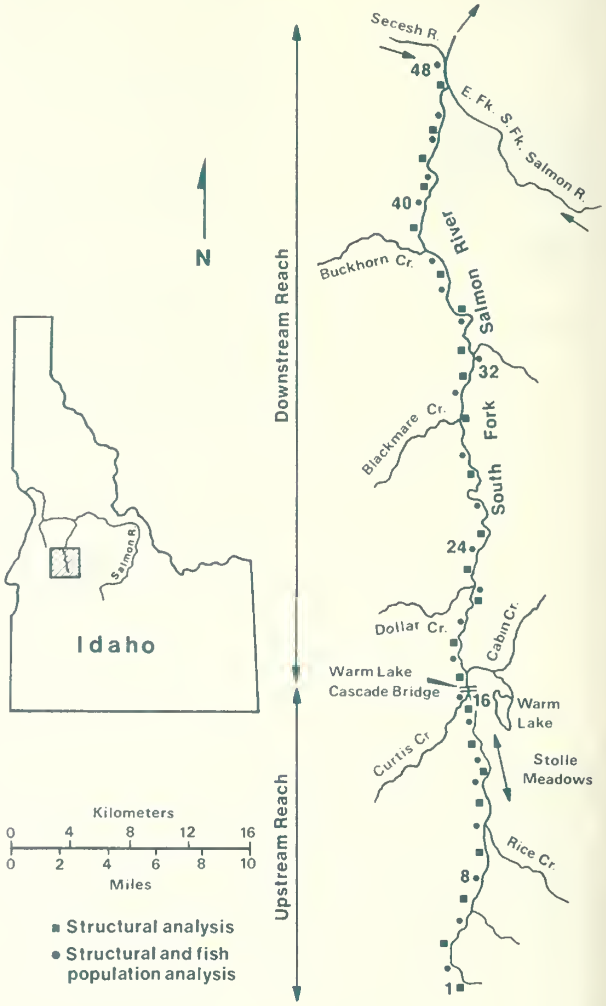

Figure 1. Location of study sites on the South Fork Salmon River, Idaho.

STUDY METHODS

Aquatic Habitat

Environmental measurements and conditions were recorded as follows:

1. Stream, pool, and riffle widths
2. Stream depth
3. Pool quality ratings
4. Stream channel materials
5. Stream channel embeddedness

Stream width along a given transect was measured to the nearest foot (0.3 m) and classified as either pool or riffle. The pools were classified as to suitability for fish environments as follows:

Description	Rating
Maximum pool diameter exceeds average stream width. Pool is more than 3 ft (0.9 m) in depth, or more than 2 ft (0.6 m) deep with abundant fish cover.	5
Maximum pool diameter exceeds average stream width. Pool is less than 2 ft in depth, or if between 2 and 3 ft, lacks fish cover.	4
Maximum pool diameter is less than the average stream width. Pool is more than 2 ft in depth, with intermediate to abundant cover.	3
Maximum pool diameter is less than the average stream width. Pool is less than 2 ft in depth and has intermediate to abundant cover.	2
Maximum pool diameter is less than the average stream width. Pool is less than 2 ft in depth and is without cover.	1

The dominant streambed material at each 1-ft (0.3-m) interval on the transect was classified as follows:

Particle diameter	Classification
12 inches or over (304.8 mm or over)	Boulder
3 to 11.99 inches (76.1 to 304.7 mm)	Rubble
0.185 to 2.99 inches (4.7 to 76.0 mm)	Gravel
0.184 inch and less (less than 4.7 mm)	Fine sediment

Channel material embeddedness was rated as follows:

Rating	Rating description
5	The gravel, rubble, and boulder particles have less than 5 percent of their perimeter (surface) covered by fine sediment.
4	The gravel, rubble, and boulder particles have between 5 and 25 percent of their perimeter (surface) covered by fine sediment.
3	The gravel, rubble, and boulder particles have between 25 and 50 percent of their perimeter (surface) covered by fine sediment.
2	The gravel, rubble, and boulder particles have between 50 and 75 percent of their perimeter (surface) covered by fine sediment.
1	The gravel, rubble, and boulder particles have over 75 percent of their perimeter (surface) covered by fine sediment.

Electrofishing

The large size of the river below the Warm Lake Bridge prevented accurate estimates of fish populations with the Smith-Root Model VII[2] backpack electrofishers. Therefore, the river section below the bridge was snorkel censused and the river section above the bridge was electrofished. The two-step depletion method as described by Seber and LeCren (1967) was used in the electrofishing. This method resulted in wide confidence intervals around the population estimates. Therefore, to make the data meaningful only the actual number of fish collected are used as the population numbers. This estimate is less than the true population. Also, unless special efforts are made, such as using the optimum voltage, frequency, and pulse to collect small fish, electrofish sampling can miss a greater proportion of the small young-of-the-year fish. Because we did not always make a special effort to collect small fish, results of our study are probably biased toward the larger fish.

During July 1977 two electrofishing collections were made at each site using three fish netters. One collection was made moving upstream through the site, and immediately another collection was made electrofishing downstream through the site. Fish from the two collections were combined to give the total fish for the study site. We estimate that we were collecting less than 80 percent of the fish in each site sampled. All game fish collected were identified, individually weighed, and total length measured. Sculpin, dace, and lamprey were sorted, counted, and each species recorded to gain total and average weights.

Snorkeling

Fish numbers and species in the downstream reach were determined by two observers who snorkeled upstream through each site. Each snorkeler observed 20 ft (6 m) of river channel. One snorkeler took 20 ft on the left side of the river and the other snorkeler took 20 ft on the right side. This resulted in a 40-ft-wide (12-m) band of river, over the 200-ft-long (61-m) site, being observed for each site. Each snorkeler made one upstream pass counting and identifying all the fish observed in that section. All snorkeling counts were made in September 1977. The actual number of fish recorded would be less than the true population number. Small fish and especially sculpin and dace were difficult to observe in the boulder-rubble substrates.

[2]Use of trade names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

RESULTS

Aquatic Habitat

In the upstream reach (sites 1–16), the mean riffle area in the even-numbered sites was 79 percent as compared to 74 percent for all study sites (table 1). Percent of riffle area was less in the downstream river reach (sites 17–48) than the upstream reach, with 51 percent at the even-numbered sites and 55 percent for all study sites (table 2). The similarity between the means from the even-numbered sites with the means from all sites suggests no bias was introduced from fish collection at only even-numbered stations.

Pool quality improved in the downstream reach because of the larger size of the pools resulting from higher stream flows. The percentage of boulder and fine sediment composing the channel surface in the downstream reach was greater than in the upstream reach, while rubble and gravel was less in the downstream reach of the river. The stream embeddedness rating was slightly less in the downstream reach.

Fish Populations

UPRIVER REACH

Fish occupied all study sites, with only bull trout occupying the headwaters downstream to site 4 (table 3). Bull trout, of which only three were young-of-the-year, accounted for 6.3 percent of the total fish collected, averaging 4.4 inches

Table 1.—Stream attributes by site for the SFSR above the Warm Lake Bridge, 1977

					Channel substrate					
Site	Width	Depth	Riffle	Pool	Boulder	Rubble	Gravel	Fine	Channel embeddedness	Pool quality
	- - - - - Feet	*- - - - -*	*- - - - - - - - -*	*- - - - - - - - -*	*Percent*	*- - - - - - - - -*	*- - - - - - - - -*			
1	12	0.2	83	17	43	7	36	14	4	1
2	11	.5	73	27	27	36	18	18	3	2
3	19	.6	79	21	26	42	16	16	3	1
4	26	1.2	50	50	0	16	52	32	4	2
5	32	.5	88	12	56	44	0	0	5	1
6	26	.7	81	19	68	28	4	0	5	2
7	32	.8	88	12	58	35	3	3	5	1
8	49	.4	80	20	2	18	55	24	3	2
9	31	1.0	68	32	0	45	35	19	3	2
10	39	.5	90	10	0	42	50	8	4	1
11	43	1.2	35	65	0	38	36	26	2	5
12	40	.7	82	18	2	79	8	10	4	2
13	42	1.3	60	40	0	26	33	40	3	3
14	49	.6	88	12	34	44	18	4	5	2
15	35	1.0	60	40	19	58	5	17	4	3
16	52	.8	85	15	4	81	10	4	5	1
Mean values										
Stations										
1–16	33.6 (10.2 m)	.8 (0.2 m)	74.1	25.8	21.3	40.1	23.8	14.8	3.9	1.9
Even-numbered stations	36.5 (11.1 m)	.7 (0.2 m)	78.6	21.4	17.1	43.0	26.9	12.5	4.1	1.8

Table 2.—Stream attributes by site for the SFSR from the Warm Lake Bridge downriver to the confluence of the Secesh River, 1977

Site	Width	Depth	Riffle	Pool	Channel substrate				Channel embeddedness	Pool quality
					Boulder	Rubble	Gravel	Fine		
	----- *Feet* -----		------------------- *Percent* -------------------							
17	65	2.3	5	95	0	29	23	48	1	5
18	53	1.4	47	53	49	28	6	17	4	4
19	63	.9	70	30	20	54	17	9	4	2
20	69	.6	93	7	7	88	4	0	5	1
21	70	.7	73	27	10	70	12	9	5	3
22	66	.8	59	41	31	49	13	6	5	3
23	64	.7	91	9	20	69	8	2	5	1
24	102	.6	88	12	24	66	6	5	5	2
25	52	1.4	29	71	61	13	6	19	4	5
26	60	1.1	60	40	67	20	3	10	5	3
27	83	1.5	43	57	31	41	8	19	4	3
28	71	1.9	0	100	13	31	25	32	3	5
29	48	1.4	27	73	48	31	6	15	4	3
30	77	1.0	0	100	2	16	35	58	2	4
31	81	.7	73	27	21	55	9	15	4	3
32	92	.6	64	36	57	36	1	7	4	3
33	135	.5	55	45	4	18	33	45	2	4
34	54	1.6	22	78	36	30	6	28	3	4
35	97	.7	60	40	5	18	50	27	2	3
36	66	.6	71	29	0	0	76	24	2	2
37	66	1.0	77	23	80	11	1	7	4	3
38	60	1.0	40	60	60	13	2	25	4	4
39	148	.4	64	36	6	86	4	3	4	2
40	131	.7	53	47	9	78	8	4	4	3
41	71	1.4	27	73	35	31	3	31	3	5
42	53	1.5	8	92	43	30	4	23	3	5
43	159	.3	89	11	3	17	68	11	4	2
44	160	.7	62	38	6	31	52	11	2	3
45	101	1.6	2	98	13	37	18	32	2	5
46	76	1.7	62	38	72	21	3	4	5	4
47	107	2.0	64	36	88	6	1	4	5	3
48	85	2.3	82	18	98	2	0	0	5	3
Mean values										
Stations 17-48	83.9 (25.6 m)	1.1 (0.3 m)	54.9	45.1	31.9	34.9	16.0	17.2	3.7	3.3
Even-numbered stations	79.7 (24.3 m)	1.1 (0.3 m)	50.7	49.3	35.9	33.7	15.3	15.9	3.8	3.3
Stations 1-48	67.1 (20.5 m)	1.0 (0.3 m)	58.1	41.9	28.4	36.6	18.6	16.4	3.8	2.8

Table 3.—Observed fish numbers and densities in the South Fork Salmon River above the Warm Lake Bridge, July 1977

Site	River area	Bull trout		Rainbow trout		Chinook salmon		Brook trout		Dace		Whitefish		Sculpin		Lamprey		Total fish	
	Ft²	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*	*No.*	*No./ft²*
2	2,200	31	0.014	0		0		0		0		0		0		0		31	0.014
4	5,080	38	.007	0		0		0		0		0		0		0		38	.007
6	5,200	16	.003	6	0.001	2	0.004	0		0		0		0		0		24	.005
8	9,760	12	.001	64	.006	214	.022	5	0.0005	5	0.0005	2	0.0002	19	0.002	0		321	.033
10	7,800	0		3	.0004	163	.021	0		0		1	.0001	139	.018	0		306	.039
12	7,920	0		39	.005	169	.021	0		2	.0002	2	.0002	206	.026	25	0.003	443	.056
14	9,800	1	.0001	20	.002	76	.008	2	.0002	13	.001	6	.0006	36	.004	0		154	.016
16	10,480	0		10	.001	98	.009	0		4	.0004	0		112	.011	2	.0002	226	.022
Total	58,240 (5 430 m²)	98	.002 (0.018/m²)	142	.002 (0.026/m²)	722	.012 (0.133/m²)	7	.0001 (0.0013/m²)	24	.0004 (0.0044/m²)	11	.0002 (0.0020/m²)	512	.009 (0.095/m²)	27	.0005 (0.0049/m²)	1,543	.026 (0.285/m²)
Percent of total		6.3		9.2		46.8		0.4		1.6		0.7		33.2		1.8			

(112.8 mm) (fig. 2). Rainbow-steelhead trout and chinook salmon first appeared in the river in the downstream direction at site 6. Site 8, which is located at the upstream end of Stolle Meadows, contained all fish species found in the river except larval lamprey (amnocoetes). At this site rainbow-steelhead trout and chinook salmon were the most numerous species, with bull trout accounting for only 4 percent of the population. Only two bull trout were observed in the remainder of the river studied, perhaps because of inability to compete with other fish species under these habitat conditions.

Juvenile chinook salmon were the most numerous fish found in the upstream reach and made up about 47 percent of the total fish collected. They were present in site 6 upstream from the Stolle Meadows, and were the most numerous salmonid in sites 8 through 16. Only sculpin occurred in greater numbers at sites 12 and 16. Somewhere between site 6 and site 4 anadromous fish were no longer present; the remainder of the river upstream is not used for the spawning or rearing of chinook salmon or steelhead trout.

One percent of the chinook salmon collected were over 3.9 inches (100 mm) in length and were classified as precocious males that did not smolt and migrate to the ocean. The rest of the chinook salmon were young-of-the-year, with an average length of 2.1 inches (54.2 mm) (fig. 3).

Rainbow-steelhead trout (resident and anadromous) comprised 9.2 percent of the fish collected. They occurred in all sites in which chinook salmon were found. Rainbow trout outnumbered chinook salmon only in site 6, the farthest upstream site in which either species was found.

Seventy-three percent of the rainbow trout collected were classified as 1-year-old fish (fig. 4). This could be expected, since part of this population is composed of anadromous steelhead trout, that will migrate to the ocean after 1 or 2 years in the river.

Sculpin were the second most numerous fish collected, making up 33 percent of the total fish collected. The actual percentage of sculpin in the total fish population is probably higher because of difficulties encountered in collecting sculpin by electrofishing. Sculpin were found in all sites where rainbow trout and chinook salmon occurred except site 6, the farthest upstream site.

Brook trout, dace, and whitefish made up less than 3 percent of the fish collected. Dace and whitefish were found in four sites and brook trout in two sites. Larval lamprey were also collected in sites 12 and 16. Brook trout were the only non-native fish found. If brook trout increase and move upstream, they might compete with the native bull trout population.

Observed fish densities in the upper river reach varied from 0.005 fish/ft² (0.054/m²) in site 4 to 0.056/ft² (0.603/m²) in site 12 (table 3). Sites 8, 10, and 12, located in the upper, middle, and lower sections of the Stolle Meadows, had the highest densities, with chinook salmon, rainbow-steelhead trout, and sculpin accounting for 95 percent of the total fish population.

Chinook salmon averaged 0.012/ft² (0.129/m²) for all sites but were the most numerous in sites 8 through 12, where they averaged 0.021/ft² (0.226/m²). These values are similar to density estimates found in the six most productive SFSR tributary streams in 1972 (Platts and Partridge 1978). The lower chinook salmon densities (0.009/ft² [0.097/m²]) found in sites 14 and 16 were still higher than the values found in the less productive tributaries (0.005 salmon/ft² [0.055/m²]) (Platts and Partridge 1978). Although higher than in the tributaties, densities of summer chinook salmon in the SFSR were not as high as in other Idaho streams. In Capehorn, Elk, and Marsh Creeks, tributaries of the Middle Fork Salmon River, spring chinook salmon densities averaged about 0.034/ft² (0.368/m²) in August 1972 and 1973 (Bjornn and others 1974). Salmon runs were higher in 1973 than in 1976 and could account for the difference. Bull trout and rainbow-steelhead trout each averaged 0.002 fish/ft² (0.018/m²) for the upstream reach. Bull trout densities were highest in the uppermost site and decreased in the downriver direction. Rainbow-steelhead trout, which were not found in

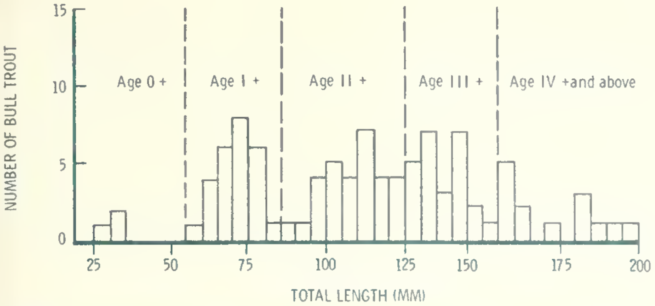

Figure 2. Length frequency of 98 bull trout collected in the South Fork Salmon River in July 1977 with estimated age classes.

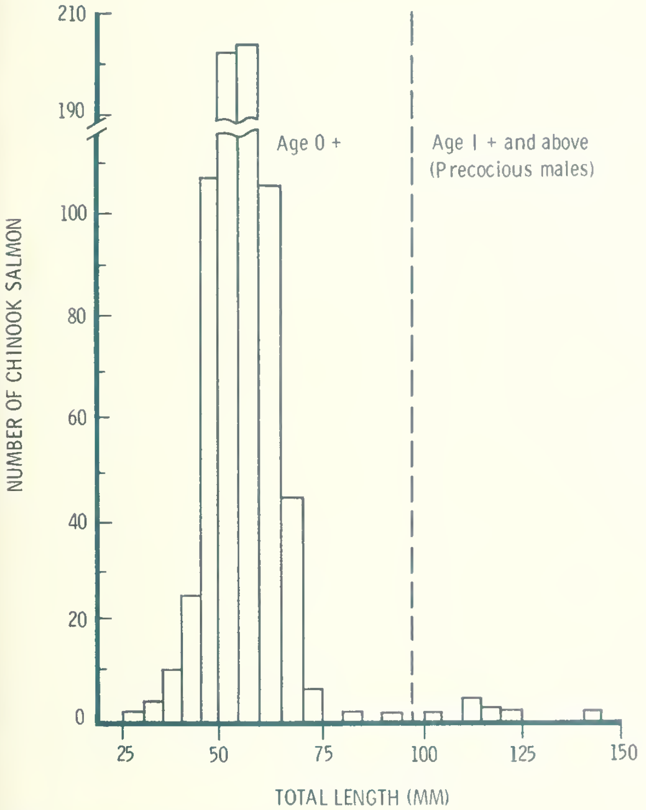

Figure 3. Length frequency of 722 chinook salmon collected in the South Fork Salmon River in July 1977, with estimated age classes.

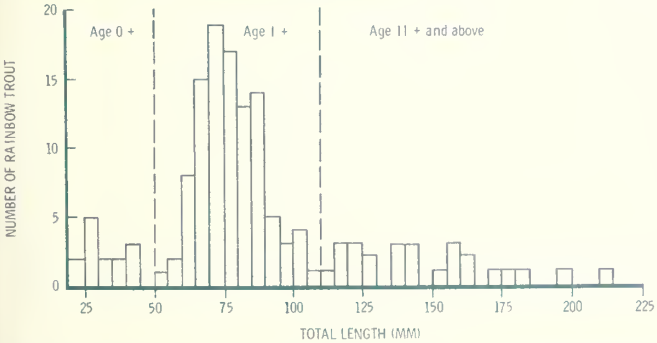

Figure 4. Length frequency of 142 rainbow trout collected in the South Fork Salmon River in July 1977, with estimated age classes.

the upper two stations, were most abundant in site 8. Rainbow-steelhead trout densities were fairly consistent except for site 10 where numbers were exceptionally low. Sculpin averaged 0.009/ft^2 (0.095/m^2) for all sites. At site 12 they were the most abundant fish, averaging 0.026/ft^2 (0.280/m^2). Brook trout, whitefish, dace, and lamprey densities averaged less than 0.001/ft^2 (0.011/m^2), although they occurred in significant numbers at some sites.

DOWNSTREAM REACH

Estimating fish numbers in the downstream reach by snorkeling proved to be less effective than the electrofishing estimates in the upstream reach. Although the water was generally clear, fish observations were hampered by physical barriers. Rubble and boulders hid small fish. This was especially evident with fish species that do not maintain themselves in the water column. Sculpin and dace were rarely seen, although they were known to be present. Because they usually occupy a higher position in the water column, a greater proportion of chinook salmon were observed than other species. Their actual and observed numbers were different, especially in riffle areas because of water depths and irregular substrates. For these reasons the information presented here for fish densities in the upper and lower sections of the SFSR are not directly comparable.

Sixteen river sites from the Warm Lake Bridge to the Secesh River were snorkeled for fish counts, with fish observed in 15 of the sites (table 4). Fish were not observed at site 42, although a large school of whitefish was observed immediately above the site.

Juvenile chinook salmon and whitefish were observed in 13 sites, although they did not always occur in the same site. Rainbow-steelhead trout were observed in ten sites, sculpin in five, dace in four, and bull trout and brook trout in one site each. Adult chinook salmon were also observed but not included in the fish numbers.

Juvenile chinook salmon were the most numerous fish observed, accounting for 49 percent of the total fish. Second were whitefish accounting for 38 percent, followed by rainbow-steelhead trout (8 percent), and dace (4 percent). Sculpin, bull trout, and brook trout together totaled only 1 percent of the fish observed. It was interesting that the west slope cutthroat trout (*Salmo clarki* Richardson) was not observed in the 45 miles of river. They occur in the tributaries and in the lower SFSR below the confluence of the Secesh. Their numbers must be extremely limited, or they would have been observed in the sampling.

Using 8,000 ft^2 (740 m^2) as the estimated area (20 ft [6 m]) in each site observed along each shoreline, a rough density estimate was established (table 4). The densities for all fish species per site ranged from 0 to 0.025 fish/ft^2 (0.269/m^2), with a mean of 0.007/ft^2 (0.075/m^2). Chinook salmon densities ranged from 0 to 0.013/ft^2 (0.140/m^2), with a mean of 0.0033/ft^2 (0.032/m^2); whitefish ranged from 0 to 0.012/ft^2 (0.129/m^2), with a mean of 0.0025/ft^2 (0.028/m^2); and rainbow-steelhead trout ranged from 0 to 0.002/ft^2 (0.022/m^2), with a mean of 0.0005/ft^2 (0.005/m^2). Edmundson (1967) observed steelhead densities of 0.005/ft^2 (0.05/m^2) on Johnson Creek, a tributary to the East Fork South Fork Salmon River. In the Lochsa River drainage, he reported higher densities of steelhead trout, ranging from 0.01/ft^2 (0.13/m^2) in Crooked Fork Creek in 1966 to 0.05/ft^2 (0.51/m^2) in the Lochsa River in 1965. Edmundson (1967) also reported a chinook salmon density of 0.02/ft^2 (0.22/m^2) in Crooked Fork Creek in 1966, much higher than we found in the SFSR.

Table 4.—Number and density (fish/ft^2) of fish observed by snorkeling in the South Fork Salmon River from the Warm Lake Bridge to th Secesh River (density calculated using an estimated 8,000 ft^2 per sample area)

Site	Chinook salmon[2]		Rainbow trout		Bull trout		Brook trout		Whitefish		Sculpin		Dace		Total fish	
	No.	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*	*No.*	*No./ft^2*
18	36	0.005	0		0		0	0.0001	11	0.001			0		48	0.006
20	11	.001	0		0		0		0		0		0		11	.001
22	26	.003	2	0.0003	0		0		2	.0003	0		0		30	.004
24	31	.004	3	.0004	0		0		8	.001	0		0		42	.005
26	46	.006	3	.0004	0		0		14	.002	0		0		63	.008
28	24	.003	3	.0004	0		0		3	.0004	0		4	0.0005	34	.004
30	11	.001	8	.001	0		0		1	.0001	3	0.0004	2	.0003	25	.003
32	44	.006	9	.001	0		0		50	.006	0		0		103	.013
34	104	.013	18	.002	0		0		77	.009	0		0		199	.025
36	0		0		0		0		16	.002	0		0		16	.002
38	21	.003	11	.001	0		0		92	.012	1	.0001	1	.0001	126	.016
40	37	.005	9	.001	0		0		13	.002	1	.0001	22	.003	82	.010
42	0		0		0		0		0		0		0		0	
44	1	.0001	2	.0003	0		0		0		0		4	.0005	7	.001
46	34	.004	2	.0003	1	0.0001	0		14	.002	0		0		51	.006
48	0		0		0		0		25	.003	1	.0001	4		26	.003
Mean		.0033 (0.0355/m^2)		.0005 (0.0057/m^2)		N.C.[2]		N.C.[2]		.0025 (0.0270/m^2)		N.C.[2]		.0009 (0.0097/m^2)		.007 (0.076/m^2)
Total	426		70		1		1		326		6		33		863	
Percent of Total	(49)		(8)		(0.1)		(0.1)		(38)		(0.8)		(4)			

[1]Does not include adult salmon.
[2]Number too small to tabulate.

SUMMARY

All of the randomly selected fishery study sites contained fish in or near them, showing that fish are using all areas of the river for rearing. The fish species composition was different in the upstream reach than in the downstream reach. Bull trout were the only fish found in the two upriver sites, but in the remainder of the river studied they were almost nonexistent. Juvenile chinook salmon and rainbow-steelhead trout were found throughout the river in almost all habitat types, except in the headwater area. The greatest fish densities were in the Stolle Meadows area. Chinook salmon were the most numerous fish found in the upstream reach, followed by sculpin.

In the downstream reach the numbers of sculpin observed were considerably lower than in the upper river; this was probably due to the snorkeling techniques, which will not determine the true size of sculpin populations. Whitefish and dace were found from the Stolle Meadows downriver to the confluence of the Secesh River. Whitefish populations were higher in the downriver reach. Brook trout numbers were small and were found mainly in the Stolle Meadows area. Larval lamprey were observed in the upstream reach where the electrofisher brought them up out of the substrate. They could not be observed by snorkeling so did not appear in the downstream reach. Cutthroat trout were not observed in the SFSR.

The aquatic habitat analysis did not reveal any correlation between any of the habitat conditions and the respective fish populations, except stream width. This tells us that either we are not measuring the correct variables or we must refine our habitat analysis. We would guess that we are not measuring the needed family of attributes to pinpoint correlations between habitat and fish populations.

As stream width increased, bull trout numbers decreased. The linear regression ($Y = a + bx$) had an R^2 value of 62 percent. This decrease was probably the result of competition with other fish species in the wider downriver reaches.

The number of species of fish in the SFSR should remain consistent over time but numbers of each species would be expected to fluctuate from year to year. Densities of anadromous chinook salmon and rainbow-steelhead trout juveniles will vary from year to year, depending on the number of spawning adults returning, the survival of their embryos and alevins, and rearing conditions faced during the juvenile presmolt stage.

Fish were found to occupy almost all areas of the river. The Stolle Meadows area was the most important site in the SFSR, per unit of area, for summer rearing of juvenile chinook salmon. The lower numbers of chinook salmon and rainbow-steelhead trout observed compared to earlier studies in the Salmon River drainage probably reflect the constantly declining anadromous fish runs into the SFSR. Based on our sample means, in July 1977 there was a minimum of 25,000 juvenile salmon rearing in the upper reach and 45,000 juvenile salmon rearing in the lower reach. Only about 4,000 juvenile rainbow-steelhead trout were rearing in the upper reaches and about 7,000 juveniles in the lower reaches. These would be minimum estimates because of the methodology used and because we captured less than 80 percent of the population. Regardless of the low capture rates, the low numbers of juveniles in 1977 could help explain their low return from the ocean as adults in 1979.

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Research Note
INT-325

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Recommendations for Selection and Management of Seed Orchards of Western White Pine

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ABSTRACT

Seed orchards of western white pine should be located on flat sites within the botanical range of western white pine. They should be planted at a 6 m by 6 m spacing, and they should be sprinkler irrigated, fertilized in August with 300 lb/acre ammonium nitrate, and sown with grass. Trees should be top pruned at 3 m and managed so that they develop three to four tops. Basal branches should be pruned to provide fire and rodent protection. A mechanical lift should be used to harvest cones when they are starting to open. Trees should be sanitized by removing all cones to decrease insect infestation. All trees should be tagged and the amount of pollen, number of cones, ripening day, and seed-germination capacity recorded for each individual tree.

KEYWORDS: seed orchards, western white pine, seed orchard management

The purpose of this paper is to provide recommendations on how to locate and manage western white pine seed orchards. Recommendations are based on data we have collected and experiences we have had in managing the Moscow Arboretum (an advanced breeding population used as a seed orchard) and the Sandpoint Seed Orchard. Data from other sources are used when pertinent. This paper is not an in-depth treatment of seed orchard technology. The reader is directed to the booklet on seed orchards edited by R. Faulkner (1975). Table 1 contrasts the two sites.

The Sandpoint Seed Orchard was established in 1960 with grafts of progeny-tested, blister rust-resistant parents (Bingham and others 1963). The grafts were made in 1959 and the orchard was planted in the spring of 1960. The purpose of the orchard was to provide seed for planting stock of western white pine resistant to blister rust. A secondary objective was to learn how to manage seed orchards.

The Moscow Arboretum was established from 1957 to 1961 and from 1964 to 1967 with western white pine seedlings that had survived intense artificial inoculation with blister rust. The purposes of the arboretum were to provide trees for advanced breeding for blister rust resistance, as a gene bank for resistance, as a source of seed for production planting, and for seed orchard management research.

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Table 1.—Contrasting factors that may reveal causes for differences of cone production between the Moscow Arboretum and Sandpoint Seed Orchard

Factors	Moscow Arboretum	Sandpoint Seed Orchard
Frost-free period	May 12-Sept. 6 (123 days)	May 18-Sept. 16 (121 days)
Precipitation	20 inches[1]	30 inches
Winter exposure	Open site with much wind damage	Protected, with little or no wind damage
Soil type	Palouse loess	Mission loam
Soil acidity	pH 7.8	pH 5.9-6.5
Ecological site	Natural grassland	Typical white pine type

[1]The Arboretum was irrigated from 1958 to 1968 and once again in 1976 following the winter drought of 1975-76. Irrigation water was the sewage effluent from the Moscow sanitation plant.

SITE SELECTION

Pick a site that is nearly flat within the best growing range of western white pine

A relatively flat orchard site will contribute to the availability of machinery for use in the orchard and to the safety of the workers. However, low level sites that do not have good cold air drainage should be avoided, as should sites with frequent downward movements of cold air. Adequate water must be available for irrigation and the site must also be secure from vandalism or Christmas tree cutters. A close labor source is a valuable asset.

Western white pine grows best and produces more cones (bigger cones with more filled seed) within the white pine type (Rehfeldt 1979; Hoff 1981). The average height of grafts at the Sandpoint Seed Orchard in 1979 was 9.5 m (31 ft); at the Moscow Arboretum, the average height of grafts of the same families was 7.3 m (24 ft) and the Moscow grafts were older. Sandpoint produced more than twice as many cones per tree as did the Moscow grafts (80 as opposed to 37).

SPACING

6 by 6 m (20 ft by 20 ft)

Trees at both the Moscow Arboretum and the Sandpoint Seed Orchard are spaced at 6 by 6 m (20 ft by 20 ft) and with pruning, as recommended below, would have a probable life of 40 to 50 years. This will likely be beyond the genetic lifetime of the seed orchard as it will probably be replaced by one with better genetic material.

This large initial spacing has made for ease in moving vehicles and equipment in the orchard. Moreover, a square or rectangular orchard enhances pollen distribution.

IRRIGATION

Sprinkler irrigation

Several orchards are using the drip method for irrigation (Wheat and Bordelon 1980). This method probably conserves water, but one advantage of sprinklers is that they can be used for frost protection. Western white pine flowers appear to be sensitive to frost (Bordelon 1978).

It is expected that irrigation will have a beneficial effect on seed production on dry sites. In 1977, a portion of the Moscow Arboretum irrigated during July of the harvest year produced 23,027 seeds per pound (10,445 per kg) compared to 26,309 smaller seeds per pound (11,934 per kg) from a nonirrigated portion.

FERTILIZER

Ammonium nitrate at 300 lb/acre Apply late August or early September

Fertilizer-irrigation studies were completed several years ago using the grafts at Sandpoint and the seedlings in a plantation near Fernwood, Idaho. The purpose was to initiate flower production. These fertilizer-irrigation treatments had no effect on cone production (Barnes and Bingham 1963; Steinhoff personal communication 1980).

Barnes (1969) did show that 300 lb of ammonium nitrate did increase cone production in trees that were already producing, and further, that the cones and seed were larger.

Schmidtling[2] believes fertilizing in August enhances photosynthesis, is too late to affect vegetative growth, and allows accumulation of carbohydrate and nitrogen favorable for flower induction. Fertilizing in September, he believes, is too late to affect either vegetative growth or carbohydrate accumulation before the formation of primordia. But, he says, the increase in nitrogen content is still partially effective in increasing flowering.

[2]Schmidtling, R. C. Fruitfulness in conifers: a critical review of the literature and recommendations for further research. 16 p. Unpublished report.

COVER CROP

Sow grass and keep it close cropped

A large rotary lawnmower will do a good job of keeping the grass low. We have also used horses (Coffen 1978). They did a good job and even ate thistles. However, on the orchard sites trees must be 15 to 20 ft tall; otherwise horses may damage the trees.

Grass will support vehicular traffic and, if cutting and growth periods are timed to produce competition for water, may be used to stress the trees in flower induction programs. Tall oatgrass was used in the Moscow Arboretum. However, Pomar dwarf orchardgrass and Durar hard fescue may be a better choice to control weeds and provide ground cover. At the Lone Mountain Plantation, Coeur d'Alene, Idaho, Pomar dwarf orchardgrass definitely had a positive effect in reducing gopher activity. Anyone wishing to use grass as a cover crop should check with the local Agricultural Extension Agent for the best grass variety for a particular area.

PRUNING

1. **Cut the leader during the growing season when the top whorl reaches 3 m (10 ft) (fig. 1A) and a 25-cm (6-in) stub can be left above the whorl (fig. 1B)**

2. **Each year, shape trees by removing only the terminal bud of any leader showing dominance (fig. 1C)**

3. **Manage trees to produce two to three stems from the 3-m height (fig. 1D)**

Trees in the Moscow Arboretum with multiple tops produce more cones and pollen than single-stemmed trees (Bordelon 1978; Coffen and Bordelon 1981). Also, trees with multiple stems in the top were not obviously shorter in height than single-stemmed trees. Blum (1980) reported that total tree height is not significantly affected by pruning. In his work on pruning softwood trees to improve wood quality, he found that removing less than one-sixth of the crown had not affected height or radial growth of trees after 9 years.

FIRE AND RODENT PROTECTION

Remove basal branches up to 2 to 2.5 m (6 to 8 ft) over several years

Remove the bottom two whorls the same year that the leader is cut (fig. 1B). Remove one whorl per year every 2 to 3 years thereafter. This will remove cover for rodents and fuel for disastrous fires. Ten to fifteen years after pruning, the orchard trees should look something like those in figure 1D as compared to an unpruned tree (fig. 1E). The basal pruning will also make it easier to move equipment around the orchard.

With the exception of increasing moisture stress in flower induction programs, the grass should be kept short enough to minimize fire risk. A firebreak should be established and maintained around the orchard perimeter. Maintenance of a short turf removes food and cover and acts as an ecological measure to limit the distribution of mammals, such as mice, ground squirrels, and rabbits, that feed on vegetative structures. Grazed or mowed grass makes it easier for avian predators to control pest populations. Kimbal and others (1970) report that the use of predators effectively controlled gopher populations around an artificial roost.

HARVEST

1. **Pick cones when they are spongy or just beginning to open**

2. **Extract seed immediately**

Not all cones mature at the same time. A 10-day to 2-week difference in the time of cone ripening among trees has been observed.

Cones collected during hot, dry weather provide seed with highest germination percentages, fastest germination, and minimal requirements for stratification. On the other hand, cones collected during cool and especially rainy periods behave differently. Even if cones were beginning to open, the process stops with the onset of cool weather. And if the cones are kept in burlap sacks, instead of being dried quickly, the seed coat may become infected with mold, which causes rotting during germination. We have controlled this mold to a degree by using a 10-minute soak in 5 percent solution of Clorox.[3] With such seed, it has been our experience that germination has been high but that the stratification process has to be just right; little variation in temperature or moisture levels has been tolerated. Further, cones and seed insects keep working until cones are dried and seed is extracted; so it is important to get extraction done as soon as possible.

In examining the importance of low seed moisture in pine, Barnett (1979) observed the following:

Seed moisture level	Response
Above 8 to 9 percent,	insects become active and reproduce.
Above 12 to 14 percent,	fungi grow on and in seed.
Above 18 to 20 percent,	heating may occur.
Above 40 to 60 percent,	germination occurs.

[3]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

A. Unpruned tree.

B. Leader was cut when top whorl reached 3 m (10 ft). The bottom two whorls were pruned at this time.

C. Pruned tree 1 year after pruning.

D. Pruned tree several years after pruning.

E. Unpruned tree of comparable age to pruned tree shown in D.

Figure 1.—Method for pruning orchard trees of western white pine for maximum production of cones.

It has been our experience that collection of white pine cones at optimum ripeness gives maximum results in goal efficiency. Waiting until the cones are starting to open on the tree may cause some seed loss. However, we feel that some seed loss is preferable to the risk of carrying less than top-quality seed through the entire growing process. Loss of even 10 percent of the harvest is a better choice economically than finding that germination is low and being forced to double or triple sow to offset poor seed performance. Low-quality seed is also bad advertising for the orchard.

While the trees are fairly short, 6 to 8 m (20 to 25 ft), with short branches, the easiest way to pick cones is to climb the trees. Only the first 3 m (10 ft) are hard to climb and this can be eased with a ladder. When the trees are bigger, especially when they have multiple tops, a climber cannot efficiently pick cones; so the purchase of a mechanical lift is justified.

A good mechanical lift that we have seen is a track-wheeled machine operated from the bucket (fig. 2). It has a 40-ft lift to the bottom of the bucket, can operate on 15 to 20 percent slopes, and move around on 40 percent slopes.

Figure 2.—A mechanical lift such as that pictured greatly facilitates orchard work.

INSECT PROBLEMS

Remove all cones from the orchard each year, both from the trees and the ground

There are several cone and seed insects that parasitize western white pine cones. Some can be very destructive. One such insect, the ponderosa pine beetle (*Conopthorus ponderosae*), overwinters in cones, but can be controlled fairly well by removing all cones (a method also recognized by Hedlin and others 1980). The beetle nearly destroyed the entire crop (400 to 500 bushels) in the Sandpoint Orchard in 1978. However, good crops of western white pine cones are so frequent that the loss of a crop or two is not serious.

Orchards on sites remote from trees of the same species will be less susceptible to heavy invasion of cone and seed insects than those surrounded by natural stands. We still recommend placing a white pine seed orchard on a natural site because we expect to get more seed per dollar invested in a shorter time, even though we know nearly all seed will be lost to insects in some years.

TAGGING

Tag each tree with its identification and location

The identification number should be embossed on a large tag (6 cm by 6 cm or so) attached to a stake. Later, the tag can be affixed to the tree or hung on a branch. The purpose of the tag is to make sure the tree number can be seen easily so that data recording will be as speedy as possible. Stakes left in the ground often are destroyed by maintenance equipment.

Some plantation managers have used heavy gage wire, such as old telephone wire, as a stake after bending it to hold the label (fig. 3A). The label can be threaded into the wire circle on the stake and be attached to the tree when the tree is large enough to accommodate it (fig. 3B).

Tree identification by row, column, and entry into a computer is a great advantage for the manager. Finding a tree in the matrix, maintaining data records, or making forms for taking data becomes routine.

A. Metal tags on old telephone wire in ground.

B. Same tag transferred to tree at eye level.

Figure 3.—Method for tagging individual trees.

DATA COLLECTION

Tabulate the following data for each tree every year

1. Tally the number of cones just before harvest and the number of pollen clusters prior to flying or estimate numbers; for example, 1 = < 10, 2 = 11 to 30, 3 = 31 to 70, 4 = 71 to 100, 5 > 100 cones or pollen clusters. Reproductive capacity is family related, meaning that a very different population of seedlings may be produced than that planned (Bordelon 1978; Hoff 1978, 1981). This record, though expensive to obtain, is a necessary check on genetic balance from the orchard (for example, see table 2).

2. Record cone ripening time by day. Some trees are ready for cone harvest when others are still unripe. A quick examination of your data will give a list of trees with early cone maturation (table 3). Information like this is an important guide for managing field crews, as well as for manipulating seed quality.

Table 2.—Average amount of pollen and cones produced per ramet in the Sandpoint Seed Orchard in 1980

Clone	Ramets	Pollen[1]	Cones
		Number	
17	103	2.7	96
19	92	1.4	88
20	68	1.0	50
21	34	1.4	36
22	107	1.6	96
24	97	1.8	98
25	20	1.6	96
37	57	1.2	62
45	61	1.4	43
58	54	2.1	87
63	11	2.5	50
65	19	1.9	72
69	25	1.0	123
86	20	1.5	55
103	16	1.8	93

[1]Pollen categories were averaged; they were 1 = < 100 catkin clusters, 2 = 100 to 500 catkin clusters, 3 = >500 catkin clusters.

Table 3.—Cone maturity on trees at Moscow Arboretum over 3 years

Maturity	Frequency	Percent
Early	112	8
Middle	891	62
Late	423	30
Total	1,426	100

3. Record germination ability. Seeds of some trees require no stratification, seeds from other trees need only to have the seed coat removed or clipped, and seeds from other trees need cold stratification (Andrews 1980). Since trees are picked individually, they could be combined according to similar seed-dormancy traits. Selection of combinations may really help the nursery phase of growing trees. For example, why stratify seed that does not need it or stratify seed for 100 days if it needs only 30?

4. Record the number of cones per bushel, seeds per pound, and percent of insect damage to cones and seeds. Such records can identify trees that are heavy producers, medium producers, or nonproducers, suffer high abortions, etc., and can provide information needed to plan fertilization, irrigation, and pest control (table 4).

Table 4.—1980 Moscow Arboretum seed crop evaluation; cones collected August 25-27, 1980

Bushel	Cones per bushel				Good seed					
	Good	Damaged	Destroyed	Total	Good cones		Damaged cones	Seed/ bushel	g/100	Seed/ml
	Number					Percent	Number			
1	95	40	6	141	3,630	93	726	4,362	2.05	22.0
2	71	61	13	145	3,010	74	1,054	4,064	2.10	21.5
3	41	39	8	88	1,740	56	1,360	2,100	2.20	20.0
4	49	28	3	80	2,117	64	1,176	3,293	2.30	17.6
5	96	52	6	154	4,141	70	1,734	5,875	2.20	20.4
6	95	29	3	127	4,576	76	1,456	6,032	2.10	20.8
7	141	2	0	143	7,548	99	44	7,592	2.00	22.2
8	101	22	23	146	4,643	88	639	5,282	2.15	21.3
9	89	25	11	125	5,100	91	500	5,600	2.25	20.0
10	101	24	9	134	5,217	90	588	5,805	2.20	23.5
$\bar{x}$	88	32	9	128	4,172	82	928	5,000	2.16	20.9

Seed production				Miscelleneous data
Seed per bushel	5,000	Seed per ml	20.9	1980 germination = 77.8 percent
Seed per gram	46.3	Seed per pound	21,053	Insect-damaged or destroyed cones = 32 percent
Seed per cone	39	Pound per bushel	.24	Total harvest = 250 bushels
Cones per bushel	128			1980 estimated production = 300 bushels

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Low and Variable Visitor Compliance Rates at Voluntary Trail Registers

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Low and Variable Visitor Compliance Rates at Voluntary Trail Registers

Robert C. Lucas[1]

ABSTRACT

Only 20 percent of the visitors to the Bob Marshall Wilderness, Mont., during 1981 complied at voluntary trail registers. Rates varied from 0 for day-use horseback riders to 47 percent for backpackers. Summer rates were seven times as high as fall rates. Unless rates are higher, trail registers do not provide a good base for use estimates. Methods of raising registration rates are discussed.

KEYWORDS: trail registers, use estimation, registration rates, wilderness, wilderness use, Montana

Unmanned, voluntary trail registers are used by managers of many wildland parks, recreation areas, and wildernesses in the United States and Canada. Their main purpose is to obtain information about the recreational use of the trails. Use estimates can be used for budgeting, for assessing the potential for impact and effects on solitude, for setting work schedules, for providing visitors accurate information about use patterns, and, in some cases, for limiting use. But, it is common knowledge that a significant proportion of visitors do not register. Therefore, adjustments to the raw trail register data are necessary to reflect actual use.

To estimate use, managers have to know what proportion of visitors register with enough accuracy to meet the management objectives served by the use estimates (Echelberger and others 1981). Usually managers also want to estimate numbers of different types of visitors—hikers and horse-users, day-users and campers, etc. Because different types of visitors comply with trail registers quite differently, managers must estimate compliance rates for each type.

There have been a number of studies of trail register compliance in different areas over the last 20 years (Lucas and Kovalicky 1981). Some studies, the early ones especially, showed fairly high registration rates, usually 70 to 90 percent (table 1).

If these high compliance rates were typical, trail register data would provide a good base for use estimates. Adjustment factors to account for noncompliance would involve only modest expansion of trail register data. Two later studies, however, found much lower registration rates (table 1). Visitors to a portion of the Selway-Bitterroot Wilderness in Montana in 1974 had only a 28 percent registration rate (Lucas 1975). The Idaho Primitive Area (now the River of No Return Wilderness) reported even lower rates, only 18 percent.[2] These low rates were an unpleasant surprise. Low rates meant expansion factors had to be large, and had to be applied to a small, shaky base. Acceptably accurate use estimates would be much harder to produce than with higher compliance.

Caution by managers was clearly called for with such divergent results. Uncertainty was high—which results were typical, which were exceptions? Was registration inherently highly variable from place to place, or were rates dropping over time? Additional information about trail register compliance rates were needed. Data now available for 1981 use of the Bob Marshall Wilderness in Montana show very low registration rates, as well as wide variations among trailheads and different types of visitors.

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[2]Personal communication, Earl Dodds, District Ranger, Big Creek Ranger District, Payette National Forest, McCall, Idaho. The estimate is based on extensive, careful field observation.

Table 1.—Reported voluntary trail registration rates, from 11 studies over 20 years

Areas	State	Year	Registration rate
			Percent
1. Three Sisters Wilderness and Mountain Lakes Wilderness	Oregon	1961-62	74
2. Mission Mountains Primitive Area	Montana	1968	65
3. San Gorgonio Wilderness	California	1969	77
4. Rawah Wilderness	Colorado	1970	89
5. Selway-Bitterroot Wilderness	Montana	1974	28
6. Idaho Primitive Area	Idaho	1974	18
7. Sawtooth Wilderness	Idaho	1975	78
8. Waterton Lakes National Park	Alberta	1976	78
9. Spanish Peaks Primitive Area	Montana	1977	50
10. McCormick Forest	Michigan	1978-79	67
11. Bob Marshall Wilderness	Montana	1981	20

(Sources: Lucas and Kovalicky 1981, table 7; James and Schreuder 1971; Leatherberry and Lime 1981.)

STUDY AREA

The Bob Marshall Wilderness is one of the country's best known wildernesses. It is large, almost a million acres, with high mountains and valleys with major rivers. It has over 20 trailheads and an extensive network of over 1,000 miles of trails. Most visitors travel by horse, and many come in the fall to hunt elk. Lengths of stay tend to be long, averaging about 5 days (Lucas 1980). In 1981, 154,000 recreation visitor-days of use were reported.

Almost all trails have trail registers, sometimes at or near the trailhead parking area, and in other cases at the Wilderness boundary, up the trail from the trailhead.

STUDY METHODS

Seven sample trailheads were chosen for sampling by personnel of the National Forests that manage the Bob Marshall (table 2). Because the primary purpose was to estimate recreational use for management planning, the trailheads believed to be most used were selected for monitoring.

Automatic electronic trail traffic counters which triggered modified movie cameras were installed on each trail. The film provided a nearly complete record of the amount and type of use from late June through mid-November. The use-monitoring equipment is described in Lucas and Kovalicky (1981). Parties were classifed by method of travel (hiking or using horses), party size, and as day-users or overnight campers, based on presence or absence of backpacks or pack horses. Visitor groups who registered were classified in the same way as on film.

Data were basically a complete census, so statistical significance is not relevant.

RESULTS

Overall, only 20 percent of the parties registered (table 2). This is one of the lowest rates reported to date, even lower than the 28 percent figure for the Selway-Bitterroot, and less than one-third the 65 and 75 percent rates reported elsewhere. Only the Idaho Primitive Area had a lower rate.

Registration rates varied widely among trailheads, from a high of 36 percent to a low of 7 percent. This variation is much greater than in previous studies.

Different types of visitors also varied in registration compliance. In general, the pattern of variation was similar to that found elsewhere, but the magnitude of variation was different. Campers complied better than day-users, but the difference (20 percent versus 18 percent) was much smaller than in other studies (table 2).

On the other hand, hikers were over 5 times as likely as horse-users to register (39 percent against 7 percent) (table 2), which is a more extreme difference than reported before. No trailhead had a registration rate for horsemen above 13 percent, while one trailhead had an 86 percent rate for hikers.

Fall visitors, mostly hunters, lowered registration rates. Only 5 percent of fall visitors registered, compared to 35 percent of summer visitors (table 2). Summer hiking campers (backpackers) had a 65 percent compliance rate, not much lower than in the earlier studies, but only 11 percent of fall backpackers registered. Only 12 percent of summer horseback campers registered, and in fall this dropped to 3 percent.

Table 2.—Number of groups observed (N) and percent registering at each of seven Bob Marshall Wilderness trailheads by length of stay, method of travel, and season, 1981

Trailhead							
Meadow Creek N = 370	Schafer Meadows N = 146	Holland Lake N = 440	Pyramid Pass N = 162	Monture Creek N = 347	North Fork Blackfoot N = 336	Bench-mark N = 420	Study area total N = 2,221
DAY-USERS							
3	5	68	26	2	13	—*	18
OVERNIGHTERS (CAMPERS)							
11	8	30	23	9	23	25	20
HIKERS							
17	19	86	41	14	32	38*	39
HORSE-USERS							
4	2	7	5	4	13	13*	7
SUMMER (late June through September 7)							
14	15	53	47	13	27	63*	35
FALL (September 8 through mid-November)							
1	0	10	6	3	12	3*	5
TOTAL (all types of use)							
9	7	36	24	7	21	25*	20

*Day-users at Benchmark are excluded because the trail register was about 4 miles beyond where use was observed. Few day-users traveled that far; therefore, they had no opportunity to register.

Method of travel and length of stay, combined, seem to affect compliance differently than each factor alone (table 3). Thus, day-use hikers had a 24 percent compliance rate[3] while camping hikers had a 47 percent rate. Day-use horseback riders had a zero rate; not **one** of 101 groups at 7 trailheads registered. In contrast, 7 percent of the camping horseback riders registered. Hikers camping with packstock—in a sense a hybrid group—had a 33 percent rate. Variation among trailheads is great.

REASONS FOR SUCH LOW RATES

One major factor contributing to the low registration rates is the mix of different types of use in the Bob Marshall. Horsemen and hunters have low rates everywhere, and they are responsible for a much larger proportion of total use in the Bob Marshall than in the other study areas. Horse-users accounted for 60 percent of the observed groups and 65 percent of the visitors (because groups of horse-users were larger than hiker groups, on the average). Half of the use came during hunting season and almost all of these visitors were hunting.

Furthermore, many of the horse-users, especially during the hunting season, are with professional guides and outfitters. Outfitters must file reports on trips with the Forest Service, and therefore almost none of them register. In 1970, 35 percent of Bob Marshall visitors used outfitters, all traveling by horse (54 percent of all horse-users were with outfitters). If the proportion of visitors with outfitters was about the same in 1981 as in 1970, perhaps private parties with horses might have a registration rate as high as 15 percent—still low.

If the studies of trail registration are compared, it appears there might be an irregular decline in registration rates over time (table 1). However, this is deceptive. All of the areas with rates below 60 percent have substantial use by horsemen and hunters; among

[3]The day-use figure for Holland Lake probably overstates compliance, because the camera/counter system was located more than 2 miles beyond the trail registers at the two trailheads that combine to serve the trail. Thus, day-users making short hikes, who had a low compliance rate, did not go far enough to be observed. If the camera had been closer, the number of parties observed would have been higher while registration data would have been unchanged, resulting in a lower compliance rate.

Table 3.—Percentage of groups registering at each trailhead, by type of use, 1981

Type of user	Trailhead: Meadow Creek	Schafer Meadows	Holland Lake	Pyramid Pass	Monture Creek	North Fork Blackfoot	Bench-mark	Study area total
				DAY-USERS				
Hikers	4	14	90	31	3	13	—*	24
Horseback	0	0	0	0	0	0	—*	0
				OVERNIGHTERS (CAMPERS)				
Hikers (backpackers)	24	25	84	56	43	50	38	47
Hikers with stock	0	100	57	20	13	71	25	33
Horseback	5	2	6	5	4	11	12	7

*Day-users excluded at Benchmark because trail register was located 4 miles beyond where use was observed.

the areas with higher rates only the Sawtooth Wilderness has appreciable use of this type. The best test of the hypothesis that compliance rates are declining would be another study of an area reported earlier to have high compliance.

Some past studies (Lucas and Kovalicky 1981) have shown higher compliance rates at stations located some distance up the trail rather than next to the parking area. This would favor **higher** rates in the Bob Marshall than in the other areas because more of its registers are located up the trail. In fact, this effect is not apparent in the Bob Marshall, and, in any case, it obviously cannot explain the **low** rates.

Trail register maintenance could contribute to poor compliance. Trail registers were serviced in the normal fashion by Ranger Districts, and I did not monitor their condition. At least two apparently ran out of cards for a few days, because some people registered on scraps of paper instead of the official cards. The importance of this factor cannot be evaluated with available information.

MANAGEMENT IMPLICATIONS

Unless trail register compliance rates are higher than reported in this paper and for the Selway-Bitterroot Wilderness and the Idaho Primitive Area, trail registers cannot provide a good base for estimating recreational use, except for backpackers. Even small fluctuations in such low rates, or errors in estimates of the rates, could easily produce use figures with errors of 100 percent or more. For example, if compliance is estimated to be 5 percent, an expansion factor of 20 is needed. If the true compliance rate was 10 percent, however, the use estimate would be twice as large as it should be.

Small errors in estimates of compliance could also produce major distortion of estimates of the composition of use and its distribution. Both of the distortions could impair management decisions.

There are several actions managers might take. First, they could try to raise registration rates. Such efforts could include better maintenance of trail registers, changes in design (brighter colors, more persuasive messages requesting registration, hitchrails for horses, better location) and education campaigns, especially with horse-users and hunters, to encourage more compliance. These groups do themselves a disservice by registering one-fifth to one-seventh as often as backpackers. Their resulting under-representation in registration records invites less consideration by managers than their true numbers would justify.

Second, if trail register information is to be used to estimate use, compliance must be checked. It should be checked at all major trailheads, because it seems to vary so much, and should be related to type of use.

Third, alternative approaches to measuring use may be better than trail registers. One alternative in some situations might be the mandatory self-issued permit, which appears to produce higher compliance than voluntary trail registers, especially for those types of visitors with the lowest registration rates (Lucas and Kovalicky 1981). Automatic trail traffic counters provide another use measurement system. If linked with cameras, they provide information about the type of use, as well.

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Using Rheology to Estimate Short-term Retardant Droplet Sizes

Wayne P. Van Meter

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Using Rheology to Estimate Short-term Retardant Droplet Sizes

Wayne P. Van Meter[1]

ABSTRACT

Airtanker delivery of fire retardant fluids causes the dispersal of many gallons of liquid into a cloud of droplets that settles onto the fuel. Measurement of the viscosity, elasticity, surface tension, and density of the fluid allows an estimate of droplet size. This information is of use in explaining the performance of various retardants and in selecting the identities and concentrations of retardant components. Results are presented for five short-term retardants and one long-term retardant.

KEYWORDS: fire retardants, rheology, viscosity, airtankers

Fire retardant liquids applied by airtankers are dispersed over the fire area in a pattern whose size and coverage density are determined in a complex way by numerous variables. The pilot can control the location (altitude and direction of flight), the airspeed, and the volume (number of tank doors opened) of an application. Beyond that, the behavior of the retardant and the consequent effect on the course of the fire depend on the physical and chemical properties of the liquid. Whether the chemical influence on the combustion process has a chance to come into play depends on the distribution of the retardant over fuel surfaces. This, in turn, is determined primarily by the sizes of the droplets in the shower produced when the retardant is dropped from a speeding aircraft.

Rheology is a science dealing with the deformation and flow of matter, involving the measurement of forces required to cause such motion and the behavior of the specimen when the force is removed. Those physical properties of fluids that are of concern here include density, surface tension, viscosity, and elasticity. Recent reports (Andersen and others 1976; Van Meter and George 1981) have described the use of these properties, measured in the laboratory, in the estimation of droplet size for specific retardant materials released from aircraft moving at various airspeeds.

There are several types of laboratory instruments that can measure the visco-elasticity of a liquid over wide ranges of the rate-of-shear. In the present instance, a Haake Rotovisco RV2 is being used to gather data on several retardant products being used by or offered for use to government agencies for the control of wildfires. This instrument utilizes a cylindrical cup containing the test fluid, and a concentric rotor immersed in the fluid. A Fisher Tensiometer is employed to measure surface tensions, and 30-ml pycnometers are used to measure densities.

The results presented in this report describe several short-term retardants. These materials contain only water and a small amount of a thickening agent which imparts a useful level of viscosity and, usually, elasticity to the mixture. These properties are beneficial in at least three distinct ways. As the bulk liquid breaks up into droplets after being released from the aircraft, the average droplet size in the cloud is significantly larger than in the case of pure water. This results in more rapid fall and less wind drift. The larger droplet size and decreased diffusion within each drop result in much less evaporative loss of water. Finally, the thickened mixture adheres to fuel surfaces better than water, retaining the cooling capacity of the material where it is needed. Some short-term retardants also tend to creep over or drain down onto fuel surfaces more readily than do the current long-term products.

Retardant products of the long-term type (high salt content) have been empirically developed to maximize performance in the field. This has taken years of operational use. Recently, these materials have been tested in the laboratory, yielding droplet-size values in the 2-mm to 5-mm range for an airspeed of 120 knots. This droplet size range is a logical point of departure for systematizing the comparison of the performance of short-term retardants with that of long-term materials.

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The figures appended to this report show results of testing six materials—five short-term retardants and one long-term retardant. They are:

Material	Manufacturer
Absorbex 2020 SLS	Absorbent Polymers, Inc.
Fire-Kill II (Xanthan gum and Kelco polymer)	Sanitek Products, Inc.
Fire-Trol STP (Nalco) (Nalco synthetic polymer)	Chemonics Industries
Short-Stop (Henkel SPG 502S polymer)	Merryhill Company
Tenogum	Charles Tennant and Co.
Phos-Chek XA	Monsanto Industrial Chemicals Co.

PROCEDURES AND COMPUTATIONS

Test specimens were prepared by stirring weighed amounts of the concentrated product into distilled water. Entrainment of air was avoided (blenders are not appropriate), and stirring was continued until the mixture was homogeneous. Specimens were stored overnight in closed jars before use. The Phos-Chek samples had been supplied by the manufacturer, with the guar gum content adjusted to 42 percent, 100 percent, and 200 percent of the amount present in the normal XA product. A measured amount of the sample is poured into the viscometer cup, and the cup is then raised into position around the rotor. Measurements of viscosity can be made at incrementally increased values of constant rotation speed, or the opposing force can be recorded automatically as a function of linearly increasing rotation speed. The elasticity is measured by observing the extent of reverse rotation of the rotor (degrees of angle) caused by the ''stretchiness'' of the fluid, after a spline in the drive system is disconnected.

A computer program has been developed which utilizes measured values of the four properties mentioned above. The density and surface tension have single discrete values for any particular liquid, but the viscosity and elasticity of a thickened retardant solution change if the fluid is undergoing shearing movement, as when being poured or being torn apart by impacting air at a high velocity.

The result produced by the computation program is a plot of the mass median droplet diameter, d_m, as a function of the aircraft velocity, V_a. Obviously, droplets of many sizes will be present in the descending retardant cloud. The size, d_m, is such that half of the mass of the retardant in any particular tankful ends up in droplets smaller than d_m, the other half in larger droplets. Measurements made by the Rotovisco instrument are subject to two sources of error. The elasticity phenomenon manifests itself as a tension within the fluid as the molecules are distorted during shearing motion. This tension dissipates quickly when shearing ceases. When the rate of shear is very high, the time required for the Rotovisco clutch mechanism to stop the rotation of the rotor is comparable to that needed for the tension to disappear. Thus, some of the reverse rotation of the rotor is lost. Also, very low shear rates result in ''plug flow,'' meaning that part of the fluid nearest the motionless cup is not moving (being sheared) at all, causing the perception of apparent viscosity to be too low. The computation program provides for the systematic exclusion of data points that might be influenced by either very high or very low shear rates.

RESULTS

The primary, and only necessary, presentation of results is the graph of mass median diameter against airspeed, discussed later. Other plots that show the differences between the several retardants tested have been prepared. These are arranged in three groups of six graphs each, each group portraying one aspect of the rheological properties of each of the six retardants. The graphs must be logarithmic because of the wide ranges of the numerical values.

The first two groups (fig. 1 to 12) deal with viscosity. The apparent viscosity is a quantitative measure of the force needed to cause shearing motion within a fluid. The dashed lines drawn through part of the shear-rate range show the estimated position of the curve for mixtures having the recommended use-level concentration. The short-term retardants, particularly Absorbex, Fire-Kill, and Fire-Trol, have noticeably lower viscosities than does the long-term Phos-Chek. (The viscosities, in poise units, are 4 to 7 times larger for Phos-Chek than for the others.) The effective viscosity graphs will be discussed later.

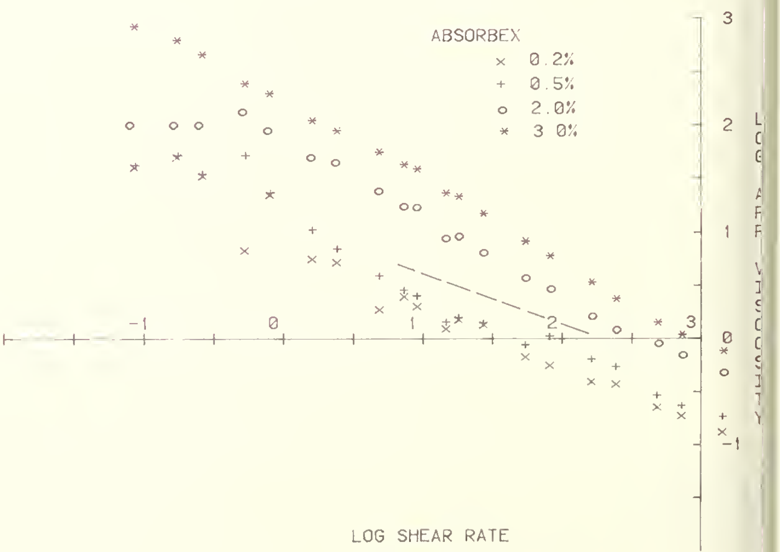

Figure 1.—Relationship of the apparent viscosity to the shear rate for several concentrations of Absorbex.

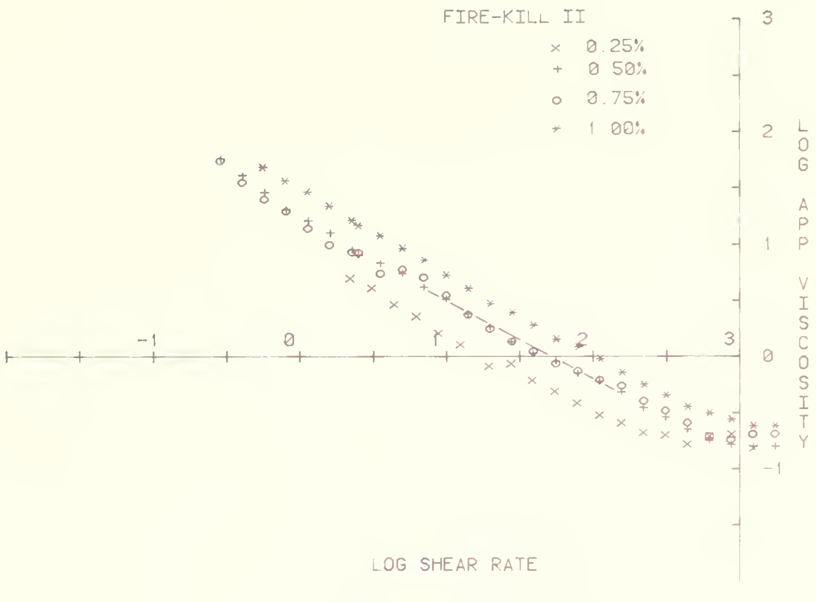

Figure 2.—Relationship of the apparent viscosity to the shear rate for several concentrations of Fire-Kill II.

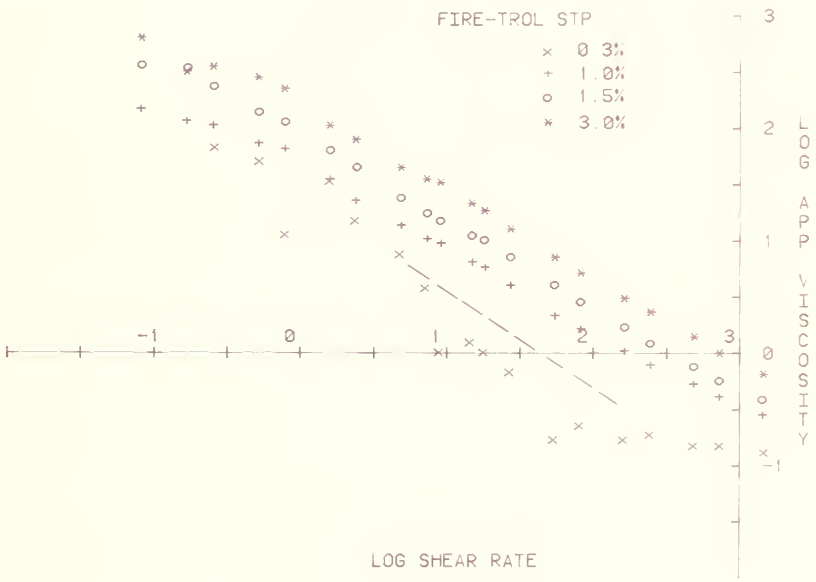

Figure 3.—Relationship of the apparent viscosity to the shear rate for several concentrations of Fire-Trol STP.

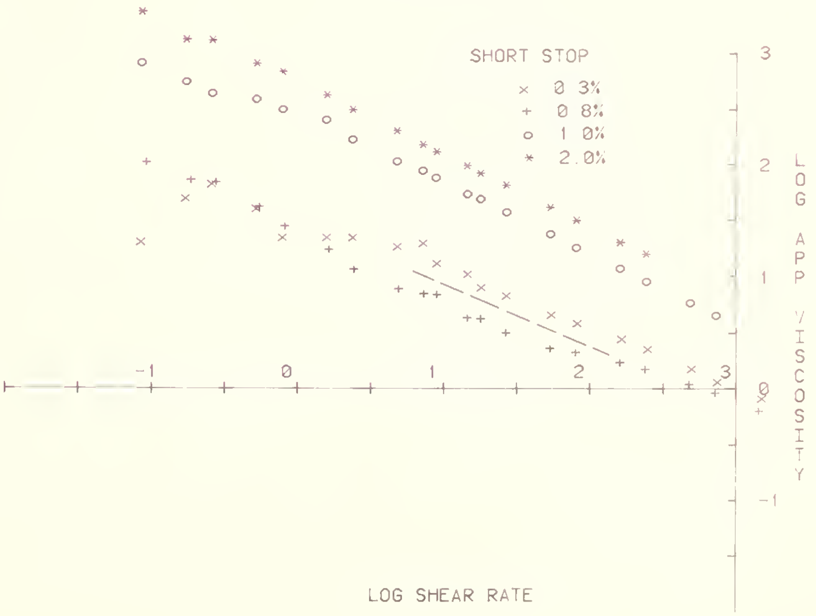

Figure 4.—Relationship of the apparent viscosity to the shear rate for several concentrations of Short-Stop.

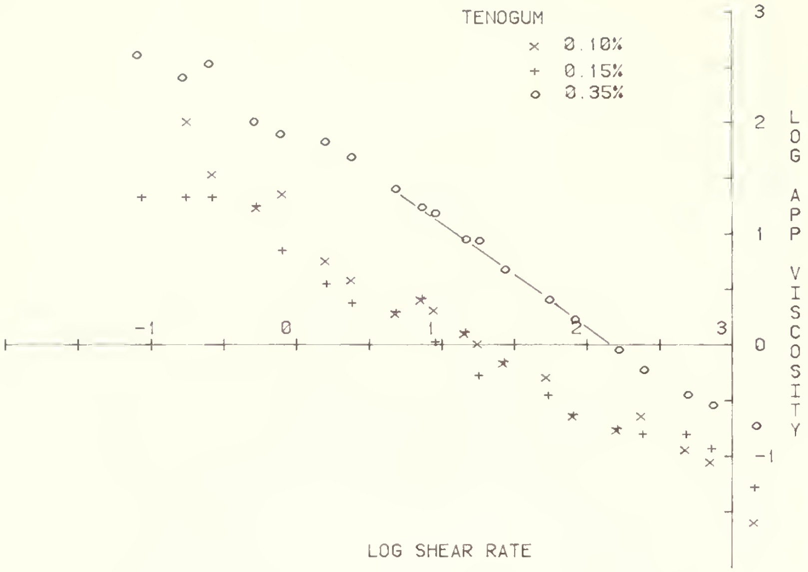

Figure 5.—Relationship of the apparent viscosity to the shear rate for several concentrations of Tenogum.

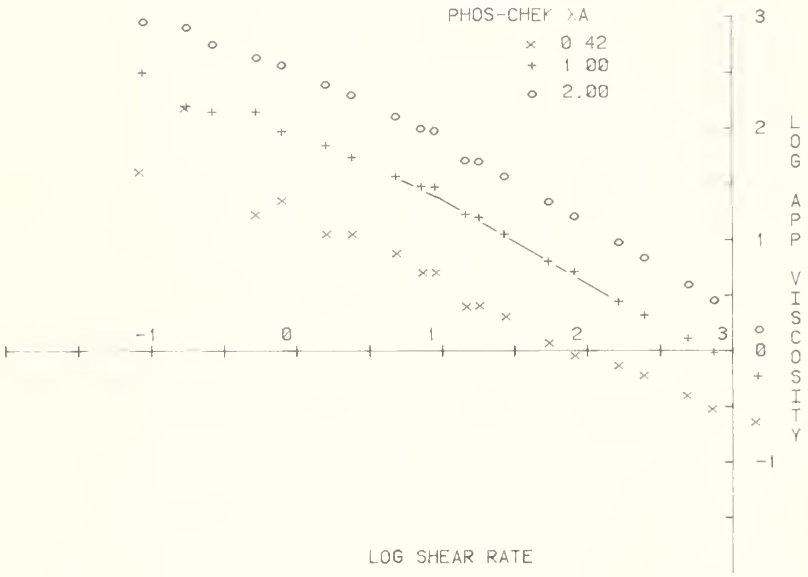

Figure 6.—Relationship of the apparent viscosity to the shear rate for three formulations of Phos-Chek XA.

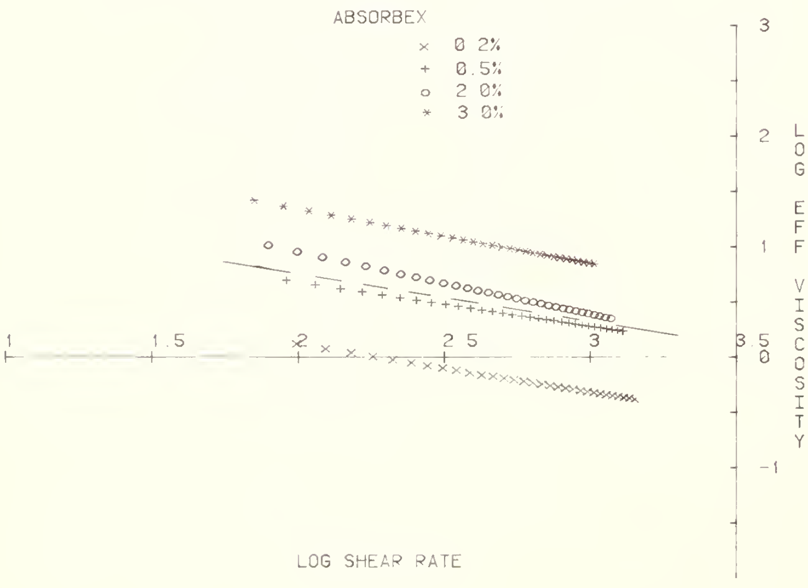

Figure 7.—Relationship of the effective viscosity to the shear rate for several concentrations of Absorbex.

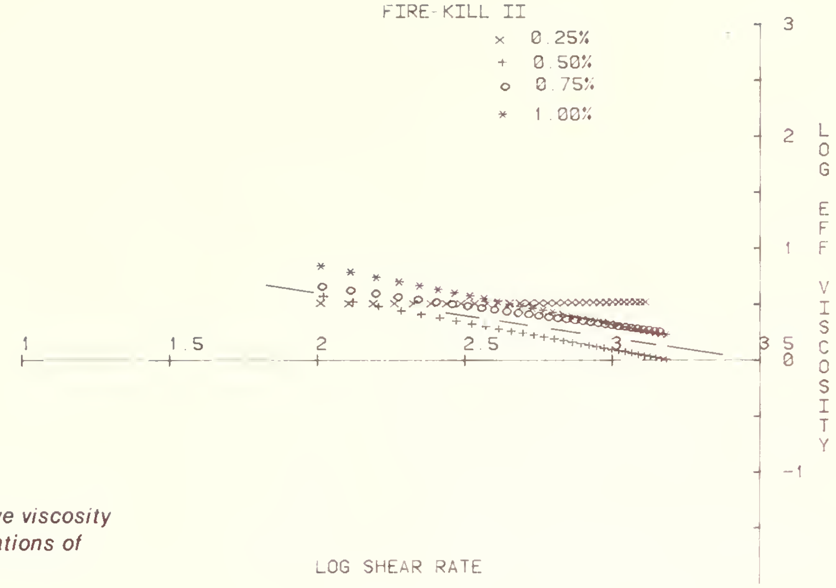

Figure 8.—Relationship of the effective viscosity to the shear rate for several concentrations of Fire-Kill II.

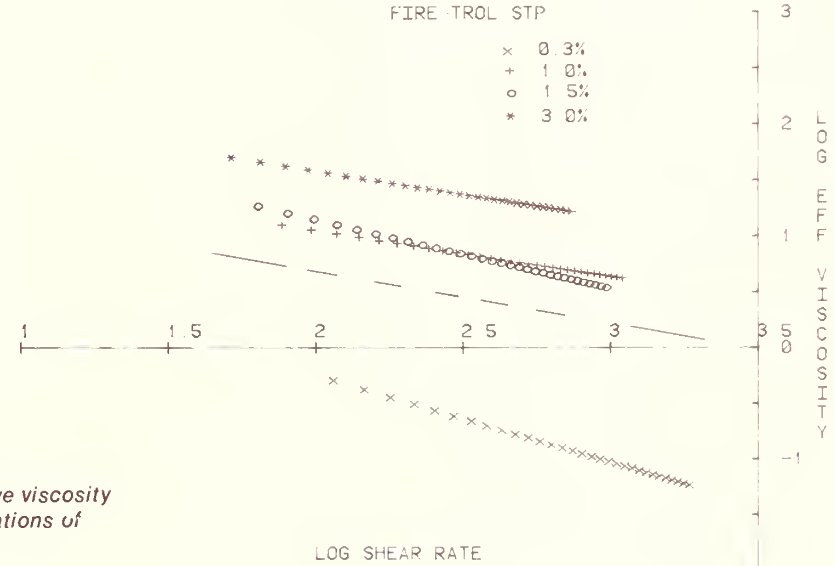

Figure 9.—Relationship of the effective viscosity to the shear rate for several concentrations of Fire-Trol STP.

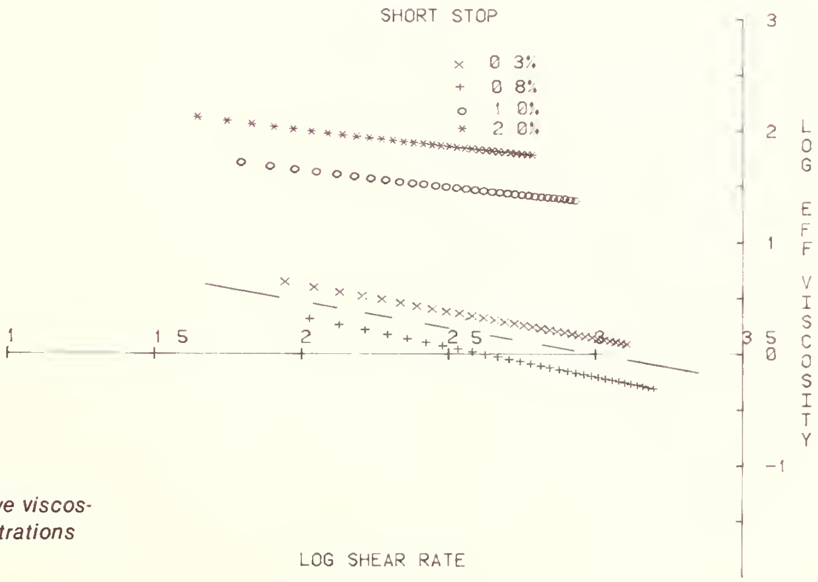

Figure 10.—Relationship of the effective viscosity to the shear rate for several concentrations of Short-Stop.

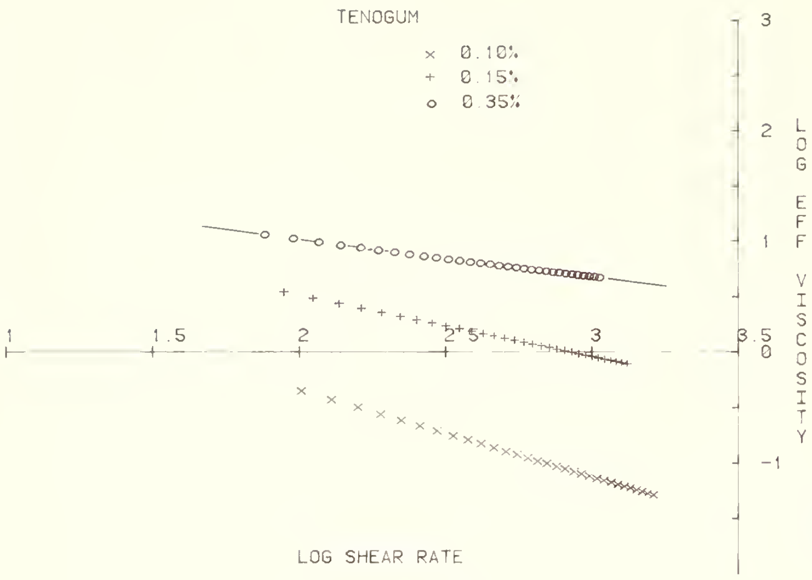

Figure 11.—Relationship of the effective viscosity to the shear rate for several concentrations of Tenogum.

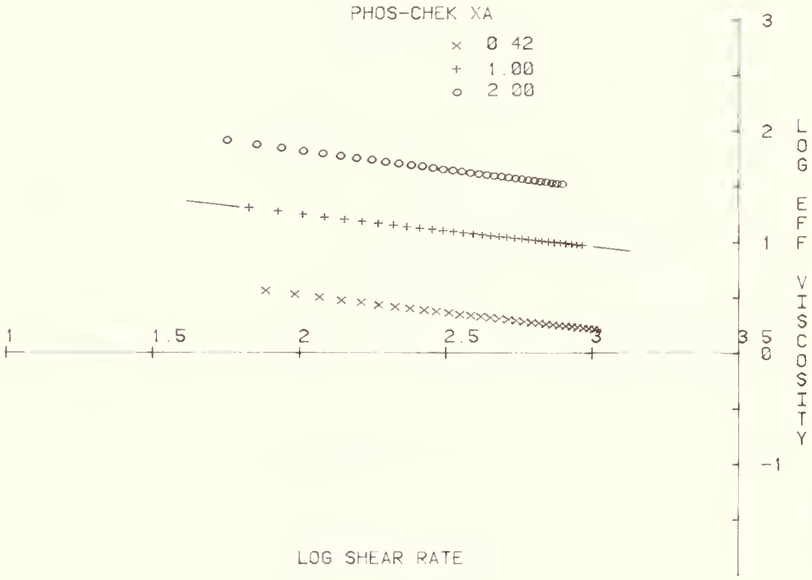

Figure 12.—Relationship of the effective viscosity to the shear rate for three formulations of Phos-Chek XA.

The property called recoverable shear ("rec shear") is a measure of the elasticity of a fluid. From the general trends in figures 13 to 18, it is apparent that Fire-Kill II has surprisingly high elasticity. There are anomalies in the sequence of curve locations in the cases of Absorbex and Tenogum. The guar gum in Phos-Chek imparts a well-known stringiness to its behavior when drops separate, but the forces tending to cause recovery of shape after deformation are comparable to those of most of the short-term retardants.

The effective viscosity at any one rate of shear is determined by both the apparent viscosity and the elasticity. The plots in figures 7 to 12 are smoothed because the computation process uses a polynomial regression and a least-squares linear correlation to produce mathematical equations describing the relationships between apparent viscosity and shear rate, and between apparent viscosity and elasticity. Because these are exponential relationships, the log-log plots are linear. As before, the solid line segments show an estimate of the result to be expected from retardants containing recommended use levels of the concentrate.

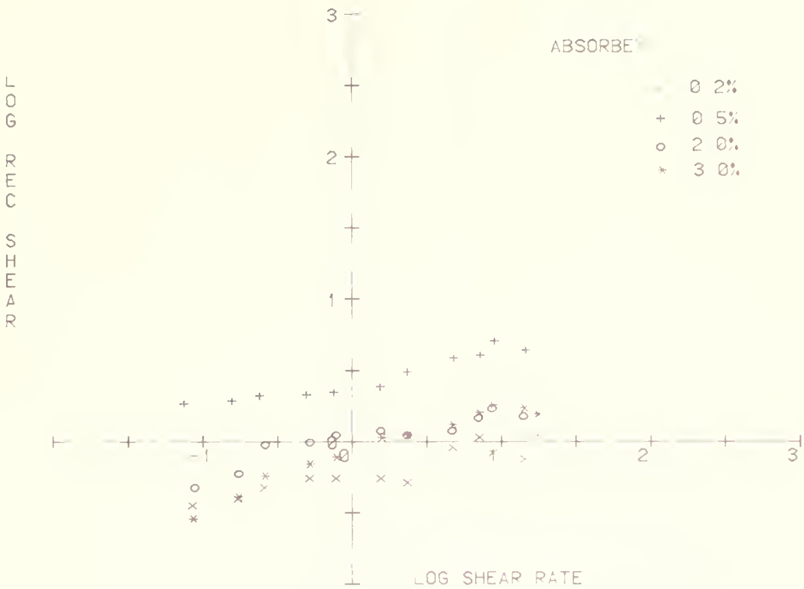

Figure 13.—Relationship of the elasticity or recoverable shear to the shear rate for several concentrations of Absorbex.

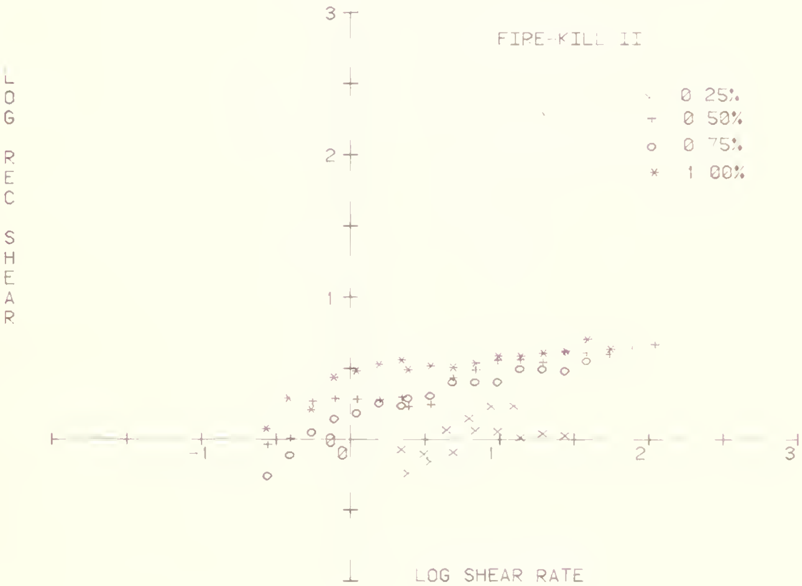

Figure 14.—Relationship of the elasticity or recoverable shear to the shear rate for several concentrations of Fire-Kill II.

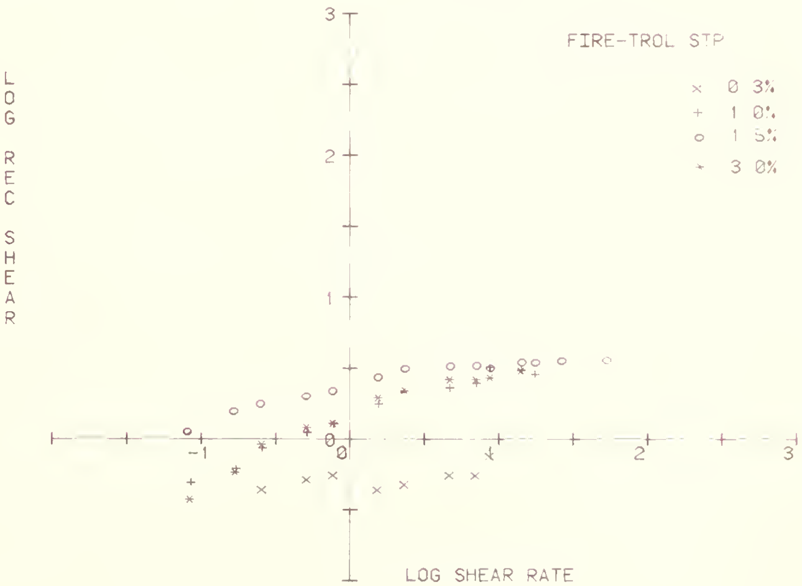

Figure 15.—Relationship of the elasticity or recoverable shear to the shear rate for several concentrations of Fire-Trol STP.

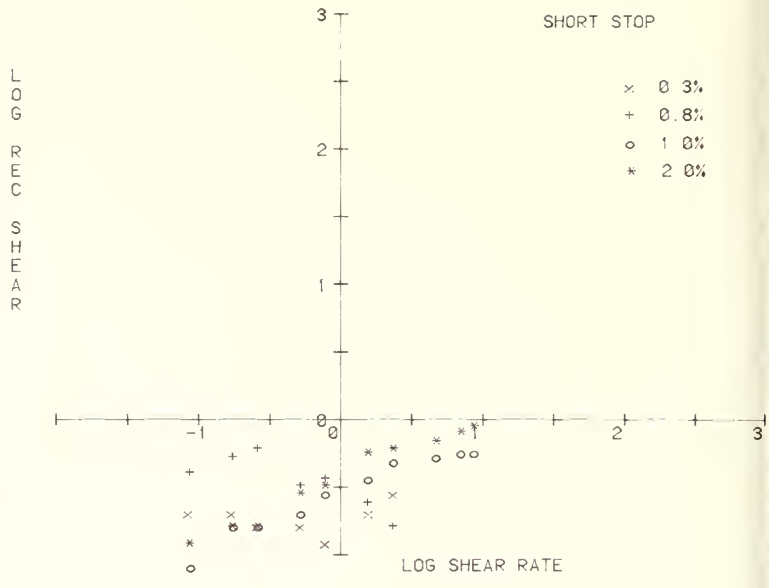

Figure 16.—Relationship of the elasticity or recoverable shear to the shear rate for several concentrations of Short-Stop.

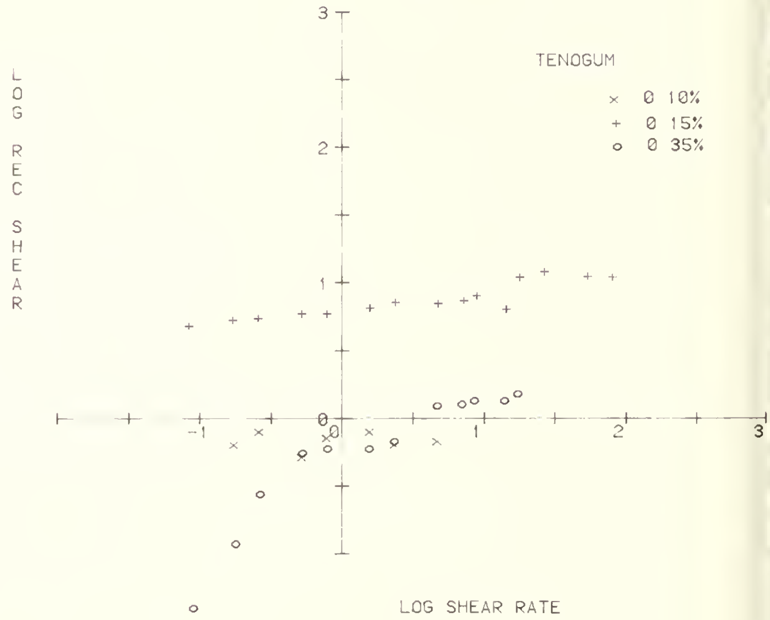

Figure 17.—Relationship of the elasticity or recoverable shear to the shear rate for several concentrations of Tenogum.

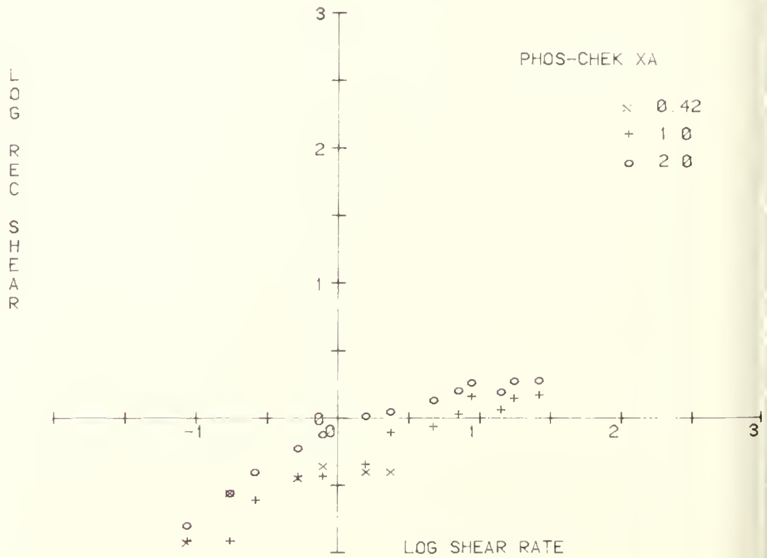

Figure 18.—Relationship of the elasticity or recoverable shear to the shear rate for three formulations of Phos-Chek XA.

Figures 19 to 25 predict the mass median droplet diameter, d_m, which would result from release of retardant at airspeeds between 30 and 180 knots. The forms of the equations that are solved to derive values of the d_m show that the apparent viscosity should be 2 to 10 times more important than the elasticity in determining the effective viscosity. The effective viscosity, with the density and surface tension, determines the mass median diameter. The experimental results confirm this, in that although Fire-Kill II and Fire-Trol STP have the highest values of elasticity (fig. 14 and 15), the fact that Short-Stop and Phos-Chek XA have the highest apparent viscosities (fig. 4 and 6) correlates with these two retardants also having the highest diameters (fig. 22 and 24). In examining the plots with respect to these comments, consider the performances at use level concentrations and the more usual fixed-wing airspeeds—90 to 120 knots.

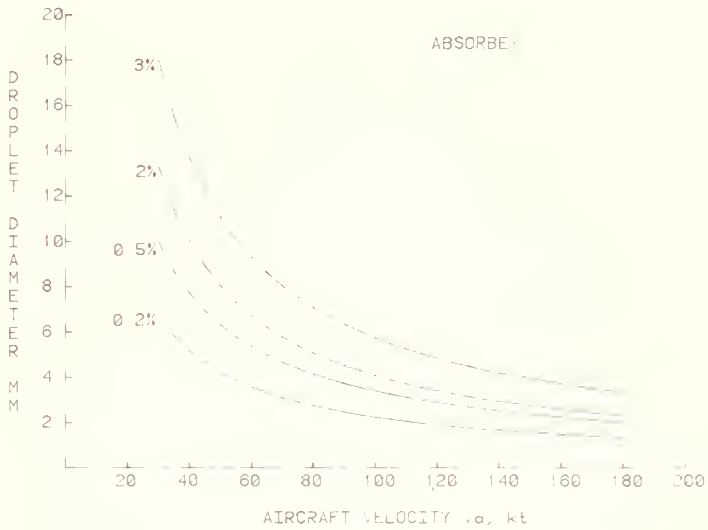

Figure 19.—Droplet diameter as a function of aircraft velocity for several concentrations of Absorbex.

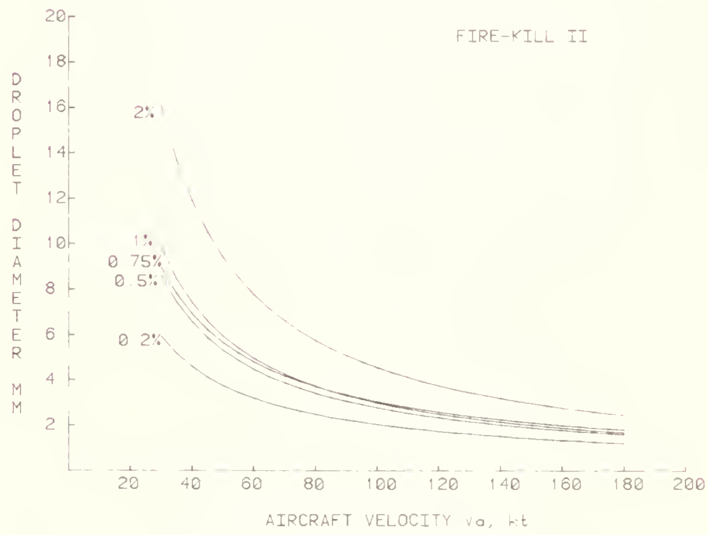

Figure 20.—Droplet diameter as a function of aircraft velocity for several concentrations of Fire-Kill II.

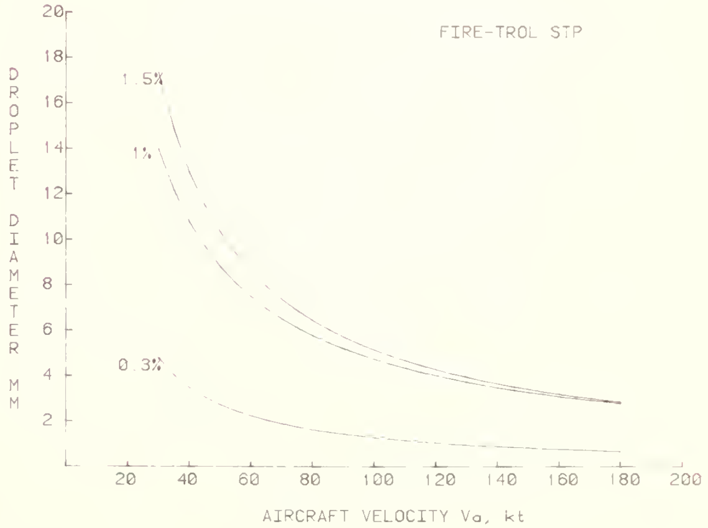

Figure 21.—Droplet diameter as a function of aircraft velocity for several concentrations of Fire-Trol STP.

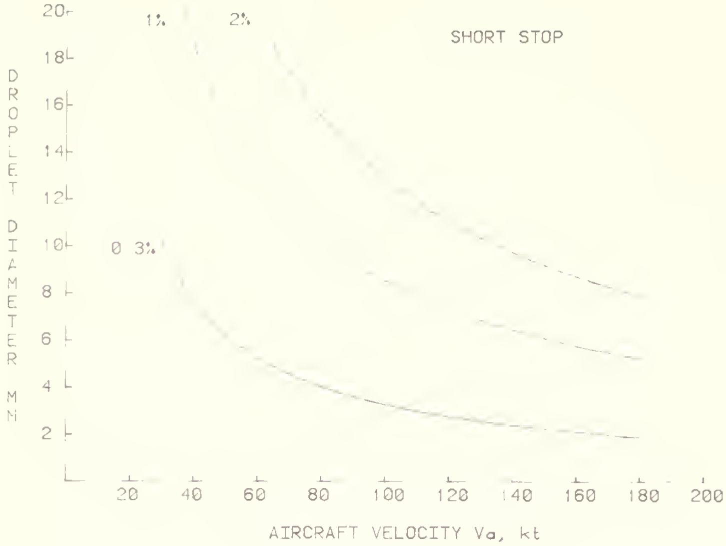

Figure 22.—Droplet diameter as a function of aircraft velocity for several concentrations of Short-Stop.

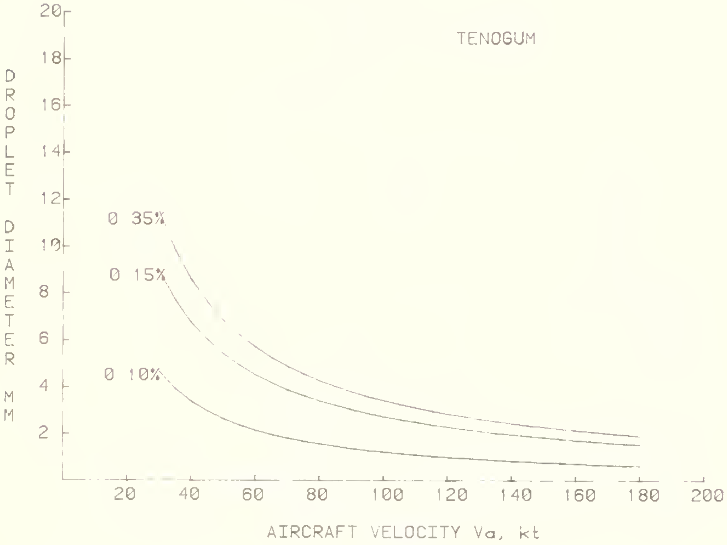

Figure 23.—Droplet diameter as a function of aircraft velocity for several concentrations of Tenogum.

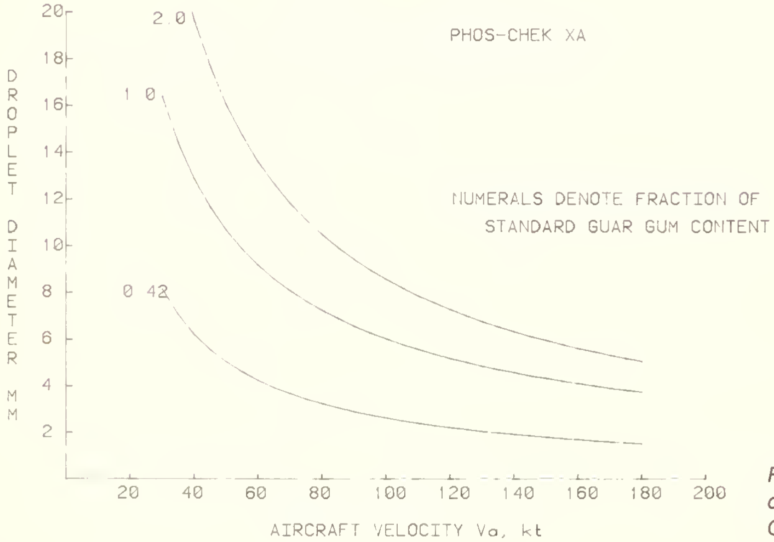

Figure 24.—Droplet diameter as a function of aircraft velocity for several concentrations of Phos-Chek XA.

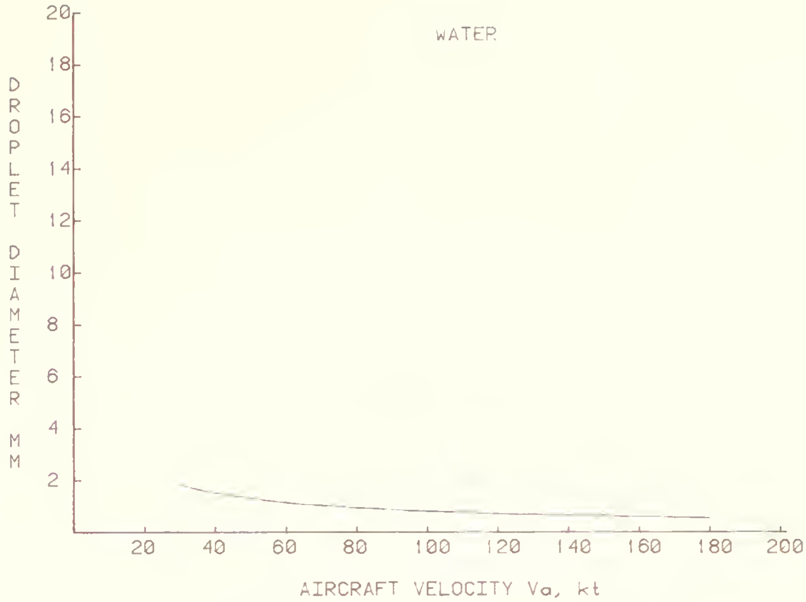

Figure 25.—Droplet diameter as a function of aircraft velocity for water.

DISCUSSION

From the graphs of figures 19 to 24, it is possible to predict the concentration that would yield a particular value of d_m when release occurs at some particular airspeed. Table 1 gives examples of such predictions. When tanker base equipment mixes concentrate with water at the time of loading the aircraft, the composition could be adjusted according to the expected airspeed and altitude at the point of release.

On a few occasions, full-scale, cup-grid field tests have been conducted, usually for the primary purpose of calibrating aircraft/tank performance, during which short-term retardants were used, as well as long-term retardants and water. Gelgard was used in some 1972 tests, but data appropriate to the comparisons being made here are not available. The particular drop tests cited in tables 2 and 3 include those in which Fire-Kill II and other fluids were dropped under the same conditions of airspeed and altitude during the several days of testing represented. The drops marked by asterisks illustrate the increasing total area of coverage as aircraft velocity increases. This effect overcomes (table 2) the expected decrease of total area as height decreases. At the same altitude and airspeed, Fire-Kill II coverages are comparable to those of Phos-Chek 259 and Phos-Chek XA. Compared to water, Fire-Kill II covers somewhat smaller total areas, with the rate of coverage shifted to higher values.

Table 1.—Concentrations needed to yield 3-mm and 5-mm droplet sizes

	Concentration, weight percent						
Retardant	Airspeed 60 knots		Airspeed 90 knots		Airspeed 120 knots		Recommended use level
	3 mm	*5 mm*	*3 mm*	*5 mm*	*3 mm*	*5 mm*	*Wt %*
Absorbex	0.15	0.45	0.3	2.3	1.	3.	0.5 to 0.66
Fire-Kill II	.2	1.	.5	2.	1.3	3.	.5 to .75
Fire-Trol STP	.4	.7	.6	1.	.8	2.5	.5 to .66
Short-Stop	.1	.3	.25	.5	.3	.7	.5 to .75
Tenogum	.12	.2	.15	.5	.35	1.	.35

Table 2.—Results of drop tests at the Northern Forest Fire Laboratory grid (Bell 206 helicopter, 90-gallon Los Angeles County tank, July 1981)

Retardant	Nominal Speed	Nominal Alt.	Total area	Coverage, gal/100 ft² 0–0.05	0.05–0.5	0.5–0.9	1–1.9	2–2.9	3–3.9	4–4.9
	Knots	*Ft*	*Ft²*	*Percent of total area*						
Water	30	150	11,000	17	30	19	26	7	1	0
*FK II	30	150	6,000	7	23	30	34	3	3	0
Water	50	120	19,400	18	48	27	7	0	0	0
*FK II	50	120	18,900	20	49	19	11	0	1	0
PC 259	50	120	17,500	24	44	17	14	1	0	0
PC 259	50	120	14,300	21	39	15	23	2	0	0
*FK II	65	100	22,600	25	55	16	4	0	0	0
PC 259	65	100	24,400	23	56	16	5	0	0	0
PC XA	65	100	25,400	27	55	12	6	0	0	0

*See text for significance.

Table 3.—Results of drop tests at the Northern Forest Fire Laboratory grid (Bell 205 helicopter, Los Angeles County tank, 1982 modifications, May 1982)

Retardant	Nominal Speed	Nominal Alt.	Volume	Total area	Coverage, gal/100 ft² 0–0.05	0.05–0.5	0.5–0.9	1–1.9	2–2.9	3–3.9	4–4.9	5–5.9	6–5.9	7–7.9	8–8.9	9–9.9	10
	Knots	*Ft*	*gal*	*Ft²*	*Percent of total area*												
Water	50	70	173	15,775	17.7	43.7	11.3	11.7	6.5	5.9	0.6	0.6	1.3	0	0.6	0	0
Water	50	70	345	26,675	15.5	39.0	9.7	15.9	6.2	4.4	2.6	1.8	2.2	1.3	0.4	0	0.9
*FK II (0.25)	50	70	173	13,775	16.3	36.2	11.6	14.7	5.8	5.1	5.8	2.2	1.5	0.7	0	0	0
PC 259	70	70	173	17,575	18.3	40.7	17.1	11.9	6.3	4.0	0.6	1.1	0	0	0	0	0
*FK II (0.25)	70	70	173	17,800	17.8	40.0	12.9	16.3	6.7	4.5	1.1	0	0.6	0	0	0	0
Water	70	120	345	29,625	8.9	30.0	25.5	30.5	4.4	0.7	0	0	0	0	0	0	0
*FK II (0.25)	70	120	173	36,625	0.8	67.4	15.3	13.2	3.3	0	0	0	0	0	0	0	0

*See text for significance.

During informal tests of Fire-Kill I in August of 1979 (Calif. Division of Forestry, Santa Rosa, Calif.) and the cup-grid tests of Fire-Kill II in July 1981 (Northern Forest Fire Laboratory, Missoula, Mont.), subjective opinions formed by experienced observers indicated that use-level concentrations yield well-formed clouds of droplets and result in wetting of grassy or brushy fuels that would contribute significantly to fire suppression.

It is especially important to remember that the d_m is not a singular description of a large portion of a droplet cloud. It is a convenient, derived number that relates to the position along the droplet size continuum of the curve (envelope) of the frequency of occurrence of all sizes. The performance expected of long-term retardants includes circumstances in which a short-term material could not suffice. Short-term retardant droplet diameters are only one-half to one-third those of, for example, Phos-Chek XA, so that they would not be expected to penetrate mature forest canopies as well. Also, if ground suppression activity cannot follow the airdrop in a short time, the short-term retardant's effects may be completely overcome by the fire. The less viscous short-term materials give adequate surface films on the fuel, and at the same time, evaporative loss is strongly inhibited. The laboratory characterization of the materials provides quantitative measures of the visco-elastic properties and allows the judgment of whether the viscosity and elasticity of a new material are sufficient. It also offers the chance to establish the use level concentration at an effective but economical value. For example, if a 3-mm mass median diameter is appropriate, and average airspeeds are in the order of 90 knots, then table 1 would infer that Absorbex, Short-Stop, and Tenogum could be formulated using about half as much thickener as is presently recommended.

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Bulldozers in Fire Management: Current Designs and Uses

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ABSTRACT

Reports on status and changes in use of bulldozers in fire control and related applications throughout the United States among Federal and State agencies. Covers various applications, changes in use, and changes and improvements in machines. Fireline production rates for new machines appear to be significantly higher than data currently in use would indicate. No significant changes in dozer use have been noted. Environmental constraints and changes in wildfire suppression policies have been implemented locally.

KEYWORDS: bulldozers, fireline construction, fireline production rates, line construction, use changes, equipment changes

INTRODUCTION

Fire management planning requires up-to-date information about the capabilities of modern machines; in this case, the bulldozer. (A bulldozer is a crawler tractor pushing an attached blade, without a plow.) This paper examines changes in bulldozers during the past 20 years, assesses the current use of bulldozers for constructing firelines in the various regions of the United States, and assesses the need to update fireline construction rates.

Bulldozers are mainly utilized to cut fire lines to mineral soil in heavy forest fuels and logging slash. Hand crews usually cannot construct lines fast enough through these fuels. Dozers are also used to prepare firelines ahead of prescribed fires; such preparation is often part of a timber harvest where the same dozers also skid logs. Dozers are often used to augment the initial attack because they are generally available within reasonable cost. Fire suppression organizations may either own or contract for machines.

Use of bulldozers has been criticized and sometimes curtailed because of environmental concerns. Damage results primarily from erosion and even gully formations in fire trails, and sometimes sloughing of slopes where trails cross steep terrain. Soil compaction and disturbance of archeological sites are also concerns. Concern for the environment may reduce dozer use and encourage alternate methods of building firelines. Such concern could also increase construction time because the firelines often have to be longer and more carefully located. For example, instead of locating a fireline straight down a steep slope adjacent to a fire, the line might be moved to a more gentle slope, resulting in a line that takes longer to construct and secure.

No exact figures are available on curtailment of dozer use, but the State of Alaska, for example, requires special permission within its organizations before bulldozers can be used to construct firelines, particularly on areas underlaid by permafrost. Alternative ways of constructing firelines are considered instead of automatically ordering dozers when planning the initial attack on a fire. Firelines around logged areas, especially on steep slopes, are currently being built by hand, with explosives, or with retardants in an effort to reduce the wide scars left by bulldozers.

EXISTING BULLDOZER DATA

Data on rates at which dozers construct fireline vary in quantity and quality, depending on the precision of the studies and the section of the Nation. The USDA Forest Service is by far the largest source of information, which is most commonly found in various "Fireline Notebooks." These data were obtained, in most instances, from machines as they existed 15 to 25 years ago. The tabulated productivity data were found to vary widely for a given type of forest fuel and among forest regions. Unfortunately, the variations found cannot be explained on the basis of soil, slope, fuel type, or other considerations (Storey 1969). Variation makes it difficult to use the production data for accurate estimates of fireline construction rates under specific circumstances of site conditions, forest fuels, and machine sizes (weight and horsepower).

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Bulldozers are compared mainly by weight and horsepower. The manufacturing trend has been toward heavier machines for a given size class. The effects of increased weight and other mechanical changes have been assessed by querying dozer operators. Some significant mechanical changes in bulldozers are (1) hydraulic rather than manual controls, (2) torque converters, (3) increased speed, and (4) increased drawbar horsepower.

Table 1 compares the changes in several machines. The older machines, for which early production data apply, were classified by drawbar horsepower (hp) and varied from 55 hp for a Caterpillar D-6[2], classed as a medium-sized tractor, to 140 hp for an International TD-24, classed as a large-sized tractor. Today bulldozers are rated by flywheel horsepower (Fw hp), and vary from 140 Fw hp for a Caterpillar D-6D, classed as a medium-sized tractor, to 300 Fw hp for a Caterpillar D-8K, classed as a large-sized tractor. There is no formula for converting flywheel horsepower to drawbar horsepower because of the many combinations of gears and torque converters. This fact made it difficult to compare the older machines with the newer ones on the basis of horsepower rating; hence, the comparisons here are limited to broad classes such as medium and large.

Weight has increased considerably; however, handling and production capabilities have also improved, according to dozer operators. The basic drawbar horsepower has also increased appreciably. The addition of such features as hydraulic blade systems has made a much more efficient machine. Operators can change the blade angle without stopping or leaving the cab. Building fireline downhill is easier and safer because the hydraulic system will keep the blade in the soil and act as a brake. Under the old cable-controlled blade systems, operators working downhill could lose their load of soil and have a downhill runaway. The new design may have undesirable effects, such as deeper scarification.

Table 2 was constructed from both published and unpublished data in an attempt to compare production rates for tractors of similar sizes through fuels classified as light, medium, or heavy. The figures appearing here are averages and have been rounded off to the nearest whole number. Even this limited sample reflects a wide variation of production rates. Part of the variation, sometimes in excess of 300 percent, is probably due to differences between and within the broad fuel type classes, as well as the more specific situations where data were collected. Although variation is relatively large, it may also be real.

Recent mechanical improvements to bulldozers have added to the variability of production rates. Because of increased efficiency, greater power, and improved handling, the newer and larger machines can outperform their predecessors. The old performance data, especially when used in conjunction with current costs and machines, can give misleading figures regarding cost effectiveness in fireline production applications today.

[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Table 1.—Bulldozer weight comparisons (from manufacturers' specifications)

Make	Model No.	Weight	Horsepower class
		Lb	
Caterpillar	D-8	46,300	Large
	D-8K	70,500	
	D-7	33,500	Medium
	D-7G	44,300	
	D-6	22,500	
	D-6D	31,500	
International	TD-24	50,300	Large
	TD-25	71,000	
	TD-18	33,200	Medium
	TD-20	47,500	

Table 2.—Fireline construction rates (single pass) for large and medium dozers in various fuel types (resistance to control) and under average conditions

Data Source	Large Dozer			Medium dozer		
	Fuel type			Fuel type		
	Low	Medium	High	Low	Medium	High
	Chains per hour					
BLM Fireline Notebook (USDI 1969)	65	25	15	40	20	10
U.S. Forest Service Fireline Notebook (USDA 1963)	No data	47	41	No data	41	30
Montana State University (Steele 1961)	34	26	13	30	24	12
California Department of Forestry (1964)	86	92	62	No data	No data	No data
California Department of Forestry (1967)	80	50	40	70	60	20
National Wildfire Coordinating Group (1980)	90	43	35	60	30	20

BULLDOZER USE IN VARIOUS REGIONS

Although environmental concerns and changes in fire management philosophies have changed some applications, dozers remain an important tool. In some areas use may have increased, while in others alternative methods have been employed on occasion. Nevertheless, the dozer is still a very useful machine in many situations.

In the following sections, a brief summary of dozer applica- ons throughout various forested regions is presented. Infor- iation was obtained through State and Federal fire manage- ient agencies. Although some of the reported use is not "soil ushing," on line-building described earlier, it is an applica- on of crawler, tracked-type machinery. Also, future trends f bulldozer use have been indicated.

;outhern States

Alabama, Arkansas, Florida, Kentucky, Louisiana, ⁄lississippi, Missouri, North Carolina, South Carolina, 'exas)

In the south, tractors are commonly used to pull plows.)ozers have push blades, too, but the plow is the chief tool f mechanized fireline building. The use is increasing omewhat due to new programs of prescribed fire and for fire revention. Kentucky indicates, however, that dozers are too xpensive and more pumper trucks are being used.

Northeastern States

Maine, New Hampshire)

In the northeast, dozers are often used in conjunction with umper trucks. The dozer use for fire suppression remains onstant, but use for prescribed burning is increasing. No en- ironmental constraints on dozer use are evident here, but and managers are being asked to consider alternatives.

;outhwest

New Mexico, Arizona, Utah)

In the southwest, bulldozer use, most popularly with Cater- illar D-7 and D-8 size categories, is increasing because of he difficulty of obtaining organized crews to construct irelines. There is also a need in this region to construct lines apidly due to highly flammable fuels. Dozers are used for ine construction in flashier fuels, especially where surface ock is not a problem. It has also been found here that ulldozer use is less costly than hand crews per chain of line. \n attempt is being made, however, to reduce bulldozer use n prescribed fires.

Alaska

Interior)

Bulldozer-constructed firelines cause extreme site damage, specially on permafrost areas. In order to minimize erosion lamage, firelines are located to avert steep slopes and fragile ites underlaid by permafrost. This slows line construction nd prevents building fireline adjacent to the burning fuels, vhich is so essential for good fire suppression practice. The lamage from dozer-constructed firelines can be severe enough hat special permission from supervisory personnel is needed efore dozers may be used. The feeling here is that explosives r other alternatives should be used wherever possible to ninimize environmental damage. Because of curtailed use, the ieed for more refined data on bulldozer construction rates loes not seem of high importance in Alaska.

Pacific Northwest

(Oregon, Washington)

Bulldozers are in constant use for fire suppression in this geographic area because of heavy fuel complexes. Dozers are extensively used on large fires as the main line-building method. They are more likely to be used where fires have escaped initial attack, rather than during initial attack. Bulldozers are often used to reopen logging roads ahead of pumper units. Preconstruction of firelines around heavy slash concentrations is also a common application.

Rocky Mountains

(Colorado, Idaho, Montana)

Bulldozers are used extensively in this region for wildfire control. They are also used for constructing firelines around logged areas prior to prescribed burning. Use in wildfire sup- pression is increasing slightly because the cost appears to be lower than for aircraft and hand crews. This is especially true on private lands where environmental restrictions are less severe than on public lands, and where heavy monetary losses are feared. Dozers still comprise an integral part of initial at- tack planning and fireline construction. Reduced use on prescribed fires is evident because of environmental damage and because of esthetic considerations. Use has been reduced on some Federal lands mainly because of concern for soil damage.

Utah and Wyoming

Dozers are used whenever possible because of relatively low cost, low-value lands, and difficulty in obtaining volunteer firefighters. Prescribed burning of 10,000 acres annually has temporarily increased the use of dozers for preconstruction of firelines, but experimental use of wet-line techniques on man- agement fires may eventually reduce tractor use.

California

Bulldozer use remains constant for constructing firelines and for constructing firebreaks along ridges and at other critical locations. An estimated 17,000 hours of annual use in- volving 55 State-owned machines is an indication of use. In California dozers are more commonly used for fireline con- struction than anywhere else in the United States.

Lake States and Midwest

(Michigan, Minnesota, Wisconsin)

Tractors with plow units are used exclusively here. Dozers with push blades alone are not a major fireline tool, though some units have both blades and plows.

General Comments

It is generally agreed in all forest regions that the environ- ment must be protected from bulldozer scars. In most regions, managers agree that after fires are controlled, dozer trails should be treated to curtail erosion. All feel that some dozer use will probably be reduced. Locating dozer lines carefully on going fires can help reduce environmental damage, but fireline construction would also be slowed.

SUMMARY AND CONCLUSIONS

Bulldozer operators who have had experience with both old and new machines report significant improvements in performance. Both the controls and the blade-lifting mechanisms are hydraulically operated, which are significant improvements. Time-trial data are needed to substantiate the claims and quantify these differences. A study is needed to determine fireline construction rates for the newer machines.

A trend toward medium-sized dozers such as the Caterpillar D–6 appears to be developing because they cost less to purchase and to operate than the larger D–8. The smaller machine, now capable of building adequate firelines in heavy fuels, is certainly preferable because it is narrower and causes less environmental damage. There are also several entirely new makes of bulldozers that need to be evaluated.

Bulldozers continue to have an important role in constructing firelines in the forest regions where they have historically been used. Bulldozer use is expected to continue, though curtailment may occur because of concern over environmental damage. Old bulldozers and new dozers are so different, both in size class delineation and control systems, that data on fireline construction rates need to be updated. Operator skill is an important variable, too, but is very difficult to measure. It is generally recognized that the operator can also make real differences in production rates.

Bulldozers have been so successful for fireline construction that continued use is probable. To maximize efficiency in future use, information should be provided on the suitability of various machines for specific jobs. Manufacturers are continually improving dozers, primarily for earth moving. Because it is impractical to design a machine of this size and cost especially for fireline construction, current models will be used for this purpose. Therefore, we should derive performance data and operating costs in simulated fireline construction situations.

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Seed Transfer Guidelines for Douglas-fir in Western Montana

G. E. Rehfeldt[1]

ABSTRACT

Regression techniques accounted for 81 percent of the variance in 3-year height of 54 Douglas-fir populations from western Montana. Seed transfer guidelines are developed from patterns of adaptive variation.

KEYWORDS: seed zones, seed transfer, adaptive variation

Artificial reforestation imposes a risk that planted trees will not be adapted to the environment in which they are planted. To reduce this risk, limits are placed on the geographic and ecologic distance that seeds are moved from their origin. These limits, embodied in seed transfer guidelines, must be based on genetic variation among populations for traits that convey adaptation to natural environments.

The present note presents seed transfer guidelines for Douglas-fir in western Montana. These guidelines were developed from patterns of adaptive variation (Rehfeldt 1982b) according to analytical techniques illustrated for western larch (Rehfeldt 1982a). These techniques assess geographic patterns of variation after effects of elevation are removed. When applied to Douglas-fir populations from western Montana, the approach accounted for 81 percent of the variance in 3-year height of 54 populations. Limits to seed transfer could then be defined as the minimum geographic or elevational interval across which differentiation was detected with a probability of about 80 percent (Rehfeldt 1979).

Adaptive Variation

Adaptive differentiation of Douglas-fir in western Montana is related to physiography and elevation (Rehfeldt 1982). Geographic patterns of genetic variation that are independent of elevation are illustrated in figure 1 by contours of relatively equal performance. A descending numeric value of contours from northwest to southeast is associated with a decreasing innate growth potential and increasing cold hardiness of populations. In addition, growth potential decreases and cold hardiness increases with the elevation of the seed source. These elevational clines, however, are steeper in the west than in the east. Consequently, adaptive variation and seed transfer must be discussed according to two physiographic zones. These zones are separated by the zero contour in figure 1.

Adaptive differentiation of populations arises from natural selection by contrasting environments. Consequently, patterns of genetic variation are closely related to environmental variation. First, as elevations increase, the length of the growing season generally decreases. Consequently, as elevation of the seed origin increases, populations display a decreased growth potential and increased cold hardiness. Second, geographic patterns of genetic variation are closely related to the climatic transitions that occur in western Montana. From northwest to southeast, a climate with a maritime component becomes continental; the frost-free period generally decreases; and precipitation greatly decreases. Patterns of genetic variation that are independent of elevation follow similar patterns (fig. 1). Most notable are relatively large genetic differences (narrow contours) that separate populations across the Bitterroot River Valley in the southwest. Here, annual precipitation decreases from 60 inches at the crest of the Bitterroot Range on the west to 20 inches slightly east of the crest of the Sapphire Mountains. And for the severe environments near the Continental Divide, differentiation in association with both geography and elevation is difficult to detect.

Seed Transfer

Patterns of genetic variation can be used to limit seed transfer by using the following information: (1) contour intervals (fig. 1) are scaled to a value of one-half the geographic distance at which differentiation can be detected (80 percent level), and (2) differences could be detected (80 percent level) between populations separated by 800 feet elevation in the western physiographic province and by 1,600 feet in the eastern province. From this information, either discrete seed zones or floating transfer guidelines can be constructed. In the western physiographic province, discrete seed zones should include two contour bands and 800 feet elevation. Transfers from a single source should be limited to ± 400 feet and ± 1 contour. In the eastern province, seed zones should include two bands and 1,600 feet elevation. Transfer from a single source should be limited to ± 800 feet and ± 1 contour.

[1]Plant geneticist, located at Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

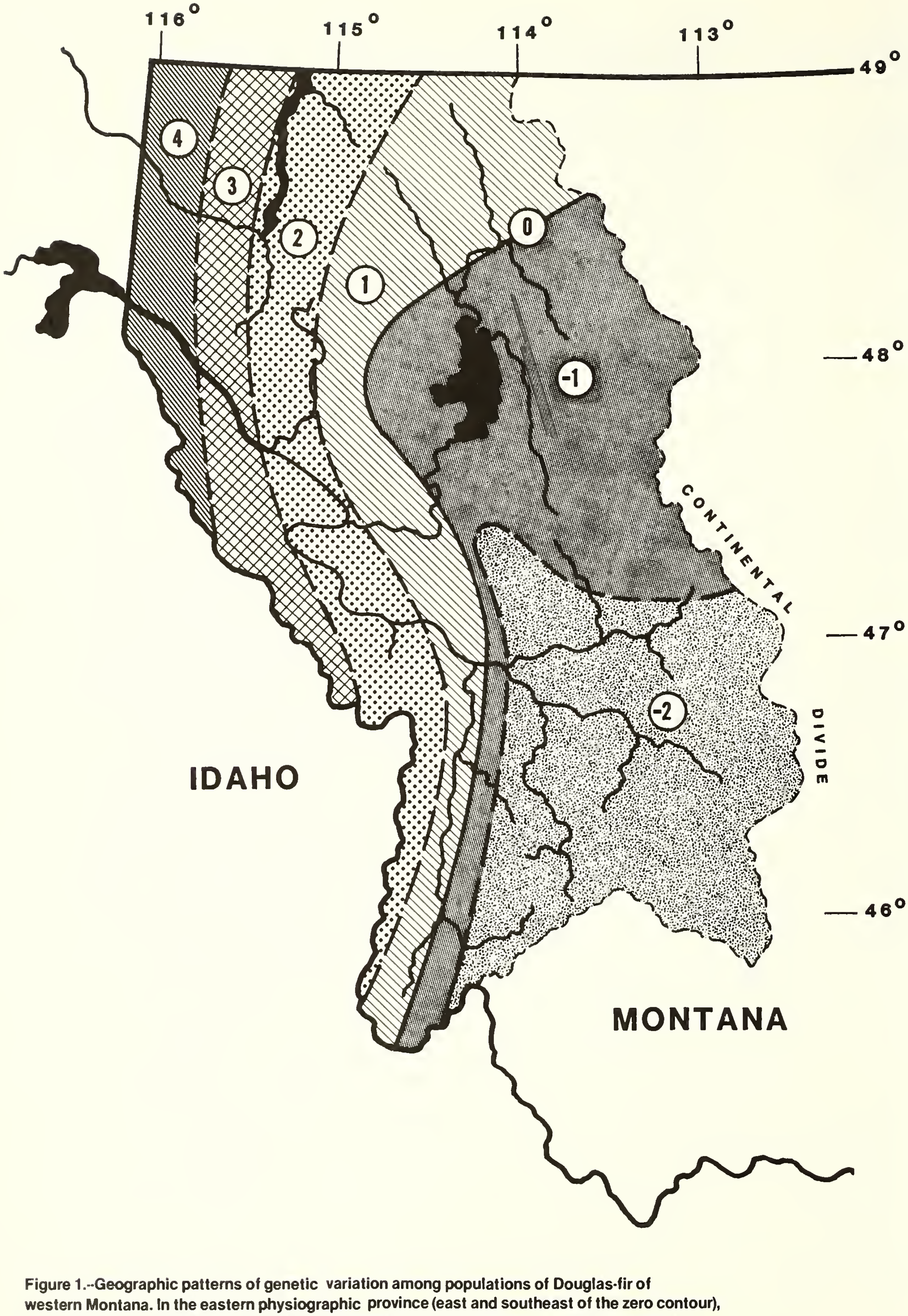

Figure 1.--Geographic patterns of genetic variation among populations of Douglas-fir of western Montana. In the eastern physiographic province (east and southeast of the zero contour), seed transfer from a single source should be limited to ± 1 contour and ± 800 feet elevation. In the west, transfer should be limited to ± 1 contour and ± 400 feet.

Floating transfer guidelines are constructed from the relationship between elevational and geographic differentiation: From the genetic viewpoint, seed transfer across 1 contour is similar to (1) a transfer of 400 feet in elevation within a western band, and (2) a transfer of 800 feet within an eastern band. Thus, seed can be transferred across contours, but each time a contour is crossed, an adjustment must be made in the elevational interval at which that seed is used. When seed is transferred into a band of lower numeric value, the appropriate elevational interval should be lowered by 400 feet for each contour crossed in the western province and by 800 feet for each contour crossed in the eastern province. When seed is transferred into a band of higher numeric value, the interval should be increased by 400 feet in the west and by 800 feet in the east.

For example, if seed is collected from 4,500 feet in band 2, the seed may be used between 4,100 and 4,900 feet (4,500 ± 400) within that band. In band 1 it may be used between 3,700 and 4,500 feet (4,100 ± 400); in band 3, it may be used between 4,500 and 5,300 feet (4,900 ± 400). When seed is transferred between zones, the zero contour should be considered as part of the western zone. In this way, floating transfer guidelines allow a single seed production area to serve several geographic bands.

Small geographic and narrow elevational limits to seed transfer may be impractical or uneconomical administratively. But, expanding the recommended limits of seed transfer increases the risk of losses in productivity in two ways: First, whenever seed adapted to a severe environment is planted in a mild environment, growth potential, as compared to local populations, is reduced. Second, whenever seed from a mild environment is planted in a severe environment, damage from the cold is increased. Estimated losses average 4 percent in 3-year height and about 5 percent in frost injuries for each contour or for each 400 feet (western province) elevation that seed is moved from its origin. There is little doubt, therefore, that even slight relaxation of the recommended limits of seed transfer can greatly alter the productivity of artificial regeneration in western Montana.

The present guidelines were developed from studies of juvenile trees. Because losses in productivity estimated for seedlings likely portend even greater losses before maturity, additional information may demand future alteration of these guidelines

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