INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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REVEGETATION OF AN ALPINE MINE DISTURBANCE: BEARTOOTH PLATEAU, MONTANA

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ABSTRACT

The first-year results of revegetation research on an alpine mine disturbance on the Beartooth Plateau in Montana are discussed. Plant densities were highest on plots treated with topsoil and fertilizer. Native seed mixtures produced higher plant densities than did introduced seed mixtures on both topsoil and raw spoil plots. Transplanting of native plants was also studied as an alternative revegetation technique. All transplants survived after 1 year, suggesting that this method offers an excellent opportunity for plant establishment on alpine disturbances.

OXFORD: 268.41
KEYWORDS: revegetation; alpine; mine rehabilitation; Beartooth Plateau, Montana; transplants

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SURFACE ENVIRONMENT & MINING
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The impacts of mineral development and of recreational uses are increasing on alpine ecosystems in the western United States. Such activities threaten to disrupt these fragile ecosystems and are already causing serious deterioration of esthetic, watershed, and wildlife habitat values in some areas. The fact that alpine tundra constitutes a relatively small proportion of the total land area in the West is in no way proportional to the importance of the impacts that disturbances have on alpine lands. Alpine ecosystems are of vital importance as metropolitan and agricultural watersheds. In addition, they contain economically valuable mineral resources, and offer popular year-round recreational experiences. These attributes dictate that research on the rehabilitation of alpine disturbances be expanded.

Although considerable research has been directed toward the study of alpine ecosystems (Osburn and Wright 1968; Ives and Barry 1974; Billings and Mooney 1968; Billings 1974; Bliss 1962; Johnson 1969; Mooney and Billings 1961), little work has been devoted to the rehabilitation of alpine disturbances.

Harrington (1946) summarized the performances of a number of plant species that were seeded and transplanted on road disturbances in Rocky Mountain National Park in Colorado. He found that both seeding and transplanting native species were successful in initiating the natural succession of vegetation.

Brink (1964) discussed various factors affecting plant establishment in alpine and subalpine regions of British Columbia. Frost action, amount of snow cover, and drought were found to be limiting factors in these environments. Willard and Marr (1970, 1971) described the rates of vegetation recovery on alpine tundra disturbed by human activities; they speculated that hundreds of years may be required to rebuild the natural ecosystem in alpine environments following severe disturbance. Belsky (1975) studied the effects of an oil spill in an alpine environment near Mt. Baker, Washington. Revegetation with cuttings of heather was more successful after 2 years than seeding with native seeds. Berg and others (1974) described many of the problems associated with the revegetation of alpine disturbances.

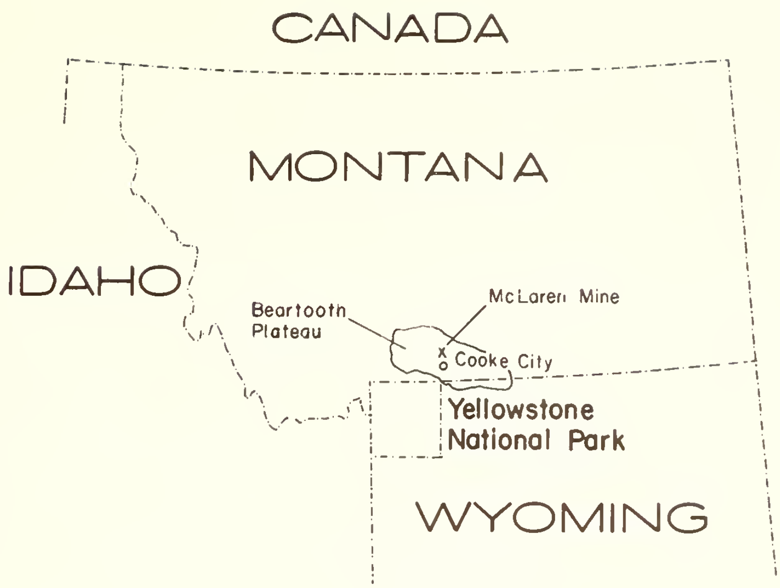
A wide variety of disruptive mining practices can be documented within the alpine ecosystem on the Beartooth Plateau. The history of mineral exploration and development in these mountains dates from near the turn of the century. Current widespread exploration for copper, chromium, platinum, and other minerals will likely result in full-scale mining operations in the near future.

The McLaren Mine located near Cooke City, Montana (fig. 1) is an example of the severe impacts resulting from mining in this area. This shallow open-pit mine was operated for the extraction of copper, silver, and gold, and has been essentially abandoned since the early 1950's except for sporadic exploration. In addition to adverse visual impacts, soil erosion and sedimentation are occurring as a result of the near total lack of a vegetative cover and the oxidation of heavy concentrations of pyritic materials is causing severe off-site water quality problems. Acid drainage is continuing to kill the native vegetation adjacent to the mine and has already resulted in the complete destruction of the aquatic ecosystem in the upper Stillwater River. This mine represents an excellent opportunity to study the effects of revegetation on a wide variety of problems related to alpine disturbances. This paper discusses the first-year results of our revegetation research on the McLaren Mine.

STUDY AREA

The geology of the Beartooth Plateau is characterized by an uplifted Precambrian granitic mass from which extensive sedimentary materials have been eroded (Bevan 1923; Loverling 1929). Basalt and acid porphyry intrusions and some limestone outcrops are evident. Most of the highly mineralized zones lie on the flanks of the main Beartooth uplift, as is exemplified by the Stillwater complex on the north and the Cooke City

Figure 1.--The McLaren Mine is located on the Beartooth Plateau near Cooke City, Montana.



ng District on the southwest. The shallow and weakly developed soils, typical of ne environments are coarse textured and rocky on the drier areas (Nimlos and others). The dominant climatic features include short growing seasons of 60 to 70 days cool summer temperatures and high solar radiation loads (Johnston and others 1975). al precipitation is estimated to range between 1,140 and 1,525 mm (45 and 60 in), of which occurs as snow during the winter months. The major alpine plant communi- on the Beartooth Plateau have been described by Johnson and Billings (1962).

The McLaren Mine is located about 8 km (5 miles) north of Cooke City, Montana, at levation of 2,950 m (9,678 ft) on a generally southwest exposure. The main ore body highly mineralized, hydrothermal pyritized-copper deposit, with primary values in , copper, and silver. The area disturbed is about 12 ha (30 acres). The mine is n alpine-subalpine transition zone, and many of the plant communities described by son and Billings (1962) are found in this area. The dominant vegetation consists erennial herbaceous plants, including grasses, sedges, and forbs. Fingers of sub- ne fir (*Abies lasiocarpa*) and limber pine (*Pinus flexilis*) intrude into the predomi- ly herbaceous alpine communities. These trees display the characteristic krummholz re of treeline environments.

METHODS

The revegetation study was initiated on the McLaren Mine in 1974. Seventy-two ots, each 2 m^2 (6.56 ft^2) were established on rough-graded mine spoil 30 m^2 ft^2) (fig. 2). Topsoil, consisting of the upper 60 cm (2 ft) of material from ively undisturbed remnant of native soil within the mine disturbance, was spread half of the study site to a depth of about 20 cm (8 in). Thus, two main plots established; each was 15 by 30 m (49 by 98 ft) in size and consisted of 36 subplots.

Selection of plant species used in this study was based on observations of natural succession on road disturbances and mine overburden piles. Some native species ay an apparent wide adaptability to establishment and growth on a variety of dis- ld sites in subalpine and alpine environments. Introduced species were selected on the basis of somewhat more limited experience.

Seed of the native species was collected from areas immediately adjacent to the McLaren Mine (table 1). The seed was cleaned and prepared in the Forestry Sciences

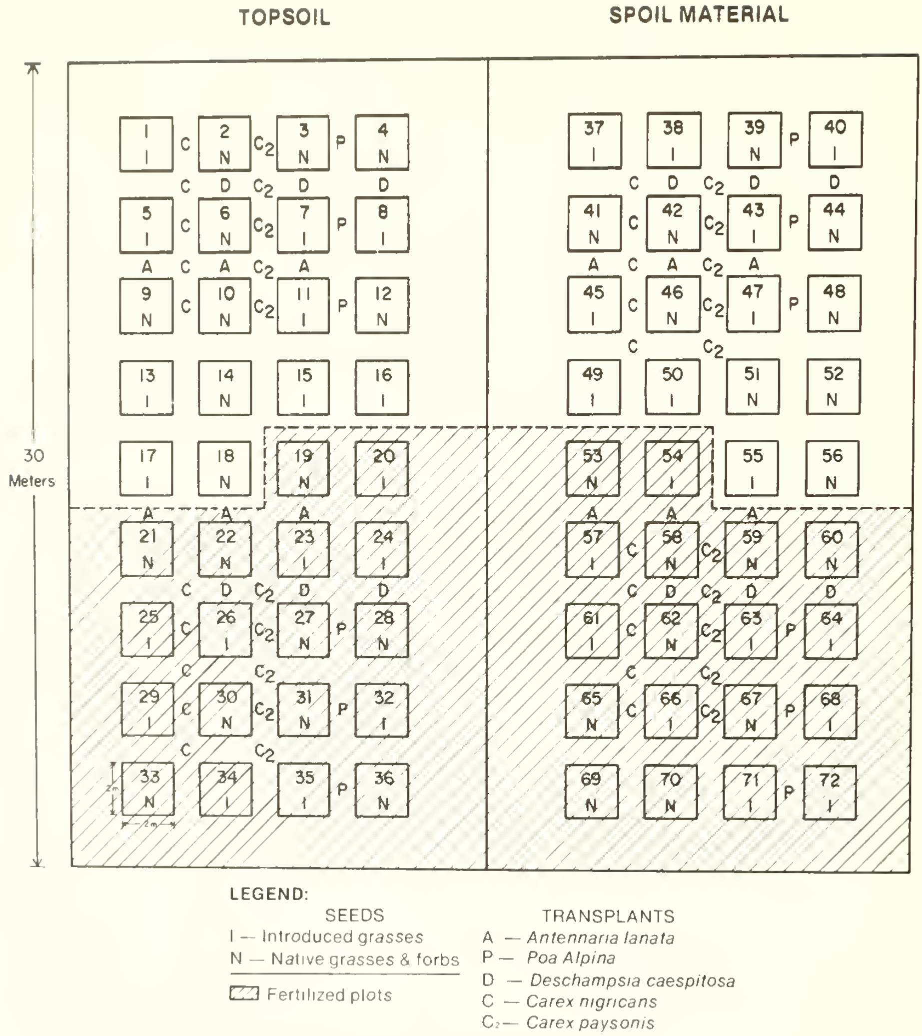


Figure 2.--Location and treatments applied to McLaren Mine revegetation plots.

Laboratory at Logan, Utah, prior to establishment of the plots. Seed of introduced species was purchased from commercial outlets, and insofar as possible, only strains that originated in the Rocky Mountain States were used.

The revegetation treatments applied to each main plot included nine replications each of four randomly located treatments: (a) mixture of seeded native species with fertilizer, (b) mixture of seeded native species without fertilizer, (c) mixture of seeded introduced species with fertilizer, and (d) mixture of seeded introduced species without fertilizer. The fertilizer used is a 16-16-16 granular mixture applied at the equivalent rate of 111 kg N per ha (100 lb N per acre). Plots were broadcast seeded in the fall of 1974 at the rate of 56 kg per ha (50 lb per acre). The percentage of pure-line seed was not determined. The fertilizer was applied after the seed. Then the plots were thoroughly raked and packed.

Table 1.--*Native and introduced species seeded on the McLaren Mine, and the seeding rates used*

Species	Seeding rate	
	kg/ha	*(lb/ac)*
NATIVE		
Tufted hairgrass *(Deschampsia caespitosa)*	17.0	(15.0)
Alpine bluebrass *(Poa alpina)*	14.2	(13.0)
Alpine timothy *(Phleum alpinum)*	14.2	(13.0)
Spike trisetum *(Trisetum spicatum)*	0.6	(0.5)
Slender wheatgrass *(Agropyron trachycaulum*[1]*)*	5.8	(5.0)
Spreading wheatgrass *(Agropryron scribneri)*	0.6	(0.5)
Woolly pussytoes *(Antennaria lanata)*	0.6	(0.5)
Mountain dryad *(Dryas octopetala)*	0.6	(0.5)
Sedge *(Carex paysonis)*	2.4	(2.0)
	56.0	(50.0)
INTRODUCED		
Meadow foxtail *(Alopecurus pratensis)*	17.0	(15.0)
Timothy *(Phleum pratense)*	8.5	(8.0)
Smooth brome *(Bromus inermis)*	11.3	(10.0)
Intermediate wheatgrass *(Agropyron intermedium)*	5.6	(5.0)
Slender wheatgrass *(Agropyron trachycaulum*[1]*)*	5.6	(5.0)
Alta fescue *(Festuca arundinacea)*	5.6	(5.0)
Orchardgrass *(Dactylis glomerata)*	2.4	(2.0)
	56.0	(50.0)

[1]Two strains of this species were used: a native strain growing near the site, and a commercially available strain.

At the time the plots were seeded, 76 transplants of native species collected from road cuts near the mine were also established. Whole, dormant plants were transplanted in rows between the subplots (fig. 2). Species transplanted were: Woolly pussytoes (*Antennaria lanata*), sedge (*Carex paysonis*, and *C. nigricans*), tufted hairgrass (*Deschampsia caespitosa*) and alpine bluegrass (*Poa alpina*).

In September 1975, 1 year after seeding, total plant density was measured on three 10-by 40-cm (3.94 X 15.75 in) quadrats systematically placed in each subplot. Depth of root penetration was observed for several plants under each treatment. Each subplot was photographed from a height of 2 m (6.1 ft); these photographs were used to determine plant cover with a dot-grid overlay. Transplant survival was determined on the basis of presence or absence of living tissue on the original plant.

Microenvironmental characteristics on the study site were monitored throughout the 1975 growing season. Factors monitored were: solar radiation, net radiation, windspeed, relative humidity, air temperature, soil-surface temperature, and soil-temperature and soil-water potential at various depths. These data were recorded at 2-hour intervals using a battery-powered, data logger system. We measured precipitation with a recording intensity rain gage.

RESULTS AND DISCUSSION

First-year results from the revegetation plots are summarized in table 2. The density of native species was significantly higher ($\alpha = 0.01$) than introduced species under all treatments. Plant densities were generally higher on fertilized plots under all treatments, illustrating the importance of fertilizer applications to first-year success of revegetation efforts. However, introduced species on the topsoil plot showed no appreciable differences between the effects of treatments with and without fertilizer. Native species were more responsive to fertilizer than introduced species on both soils.

Plants growing on fertilized plots were taller and had deeper root penetration than the same species on unfertilized plots. Deeper root penetration apparently increases seedling survival during periods of midsummer drought. Microenvironmental data collected at the McLaren Mine site indicate extended periods of severe soil water deficiences. For example, soil water potentials of -30 bars were measured in the upper 15 cm (6 in) of soil during early August. Below-freezing soil temperatures were measured, and needle ice formation was observed during the growing season. Deeper root penetration may limit frost heaving of seedlings under these conditions.

Total plant cover was very low after one growing season, even on plots where plant density was highest. It was virtually impossible to make valid estimates of plant cover because the plants were so small, and in some cases, the density so low. The highest cover estimated for any treatment was about 2 percent, which occurred on the topsoil-native-fertilizer treatment. All other treatments had lower percent cover.

All transplants, which included five species, survived and were actively growing after 1 year. The mature plants selected for transplanting had extensive root systems and crown development, and apparently were capable of tolerating greater microenvironmental stress than were seedlings. Germinating seedlings are more sensitive than mature plants to periods of severe desiccation, frost heaving, and other environmental hazards. Therefore, the use of transplants may more nearly insure rapid plant establishment and development on alpine disturbances.

It would be impractical to consider using transplants to establish an immediate, complete cover on any disturbance. A fairly large percentage of the soil surface will remain unprotected from erosion processes until lateral growth of the transplants extends into the open spaces. As yet, little is known about the rate of lateral spread by transplants; so it is difficult to assess the relative advantages of the two revegetation methods (transplanting versus seeding) for establishing a complete ground cover. Also, little research information has been published about the possibility of using various combinations of the two methods.

Some characteristics of the spoils and topsoil before the plants were established are summarized in table 3. These data are presented only to contrast the differences between the spoil and topsoil materials. Unfortunately, few data are available as to the acid and heavy metal tolerances of the species used. Of particular importance are

Table 2.--*First-year results of plant density on the McLaren Mine revegetation plots (average number of plants per m²)*

Species	Topsoil		Spoil	
	Fertilizer	No fertilizer	Fertilizer	No fertilizer
Introduced	360	401	84	26
Native	1,306	1,044	895	96

Table 3.--*Results of pretreatment analysis of native topsoil and mine spoils materials on revegetation plots*[1]

Planting sites	pH	>2mm	Organic matter	Kjeldahl nitrogen	NO_3-n	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	$HClO_4$ digest Fe	$HClO_4$ digest Al	$HClO_4$ digest Zn	$HClO_4$ digest Cu
		percent			*P/M*	-----*meq/100 g*-----				*Percent*		---*P/M*---	
Spoils	3.8	54	0.9	0.06	0.9	0.1	1.6	0.2	0.2	24.5	4.6	108	1,012
Topsoil	5.0	46	2.4	.13	.5	.2	3.6	.4	.2	14.6	2.8	99	975

[1]Analyses were performed by the Utah State University Soil Testing Laboratory and followed methods outlined by Chapman and Pratt (1961).

the low pH, high percent coarse fragments, low nutrient levels, and high concentration of such heavy metals as iron and aluminum. One year after planting, no significant changes in soil characteristics were noted except that the concentrations of N, P, and K were higher on the fertilized plots.

Various soil problems on disturbed areas that may be limiting to revegetation efforts are inherent in alpine environments. These may include low fertility, low cation-exchange capacity, poor water-holding characteristics, and low soil pH and associated heavy metal toxicity. Although native species may be climatically adapted, soil limitations may preclude successful establishment and survival. However, these soil limitations can be at least partially improved by the use of various amendments.

In addition to the limiting characteristics of the mine spoils, certain microenvironmental factors seem to contribute to the poor conditions for plant growth. On the McLaren Mine, midgrowing season drought apparently caused a high mortality of developing seedlings. The average annual precipitation on the McLaren site is at least 1,200 mm (47 in), which occurs mostly as snow. However, during the 1975 growing season (late July through early September) total precipitation was only 14 mm (0.6 in). This together with high solar radiation flux densities (maxima of 1.8 cal cm^{-2} min^{-1}, but averaging 1.3 cal cm^{-2} min^{-1}) and variable high winds (maximum 63 km/h (101 mi/h), but averaging 6.8 km/h (11 mi/h)), contributed to the low soil-water potentials measured on the plots. These data illustrate the relatively severe microclimate conditions on the plots and indicate the high evapotranspiration potentials and high soil water stresses in the plant environment.

CONCLUSIONS

Native species are apparently better adapted for revegetation of alpine disturbances than are introduced species. The native plants are at least climatically adapted and are more capable of surviving periods of environmental stress that may be unique to the area. Fertilizer improves plant growth and survivial of first-year seedlings, and should be incorporated in all revegetation efforts in alpine environments. However, the degree of plant development after one growing season will be minimal at best because of the severe nature of both the climatic and soil environments. Transplants of native species appear to offer a highly successful alternative to seeding. Although our data are only first-year results, they do tend to support these observations. If native species are to be used extensively, however, there is a need to develop nurseries for the large-scale production of plants and seeds.

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NUMBER OF PLOTS REQUIRED FOR MEASURING PRODUCTIVITY ON MOUNTAIN GRASSLANDS IN MONTANA

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ABSTRACT

The relation between the number of 4.8-ft^2 plots used and precision in sampling production is shown for 12 grassland and shrubland habitat types. Total production and production of the graminoid class (grasses and sedges) can be determined with 80 percent probability of coming within ±20 percent of the population mean by using no more than 10 plots on most of the habitat types. The forb and shrub classes, as well as individual species, are usually more variable and require substantially more plots for this level of precision. The need for range examiners to consider sampling accuracy when interpreting production data is stressed.

OXFORD: 268; 268.5; 524.63
KEYWORDS: sample size, grassland sampling, mountain grasslands; plot sampling; production estimates

The grazing capacity and degree of utilization on various range types within a grazing allotment are often determined by estimating or actually clipping vegetation from plots. Unfortunately, many range examiners tend to overlook the relationship between natural variability in vegetation and sampling requirements for reasonably precise estimates of productivity. The general instructions in Forest Service range analysis handbooks regarding plot numbers seldom indicate anticipated precision levels obtainable with the number of plots recommended. Unless the examiner statistically analyzes the variability of his data, he is unable to judge the accuracy of his production determinations. Consequently, he will lack perspective in using these data for evaluating grazing capacity.

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[1]Plant Ecologist located at the Intermountain Station's Forestry Sciences Laboratory, Logan, Utah.

The purpose of this Research Note is to show the relationship between sample size (number of plots) and precision of measuring production on 12 mountain grassland and shrubland habitat types[2] common to western Montana. This information should help the range manager obtain a more realistic view of the validity of his production determinations on these and similar habitat types.

Information presented in table 1 was developed from data obtained during a study to determine forage productivity and variability on important habitat types. Ten of the 12 habitat types are represented by three stands selected to span the range in productivity potential for the respective habitat type; the remaining two habitat types are represented by only two stands in each. A sampling technique combining estimation (40 plots) and clipping (10 plots) was used to determine production. The 10 clipped 4.8-ft^2 circular plots were randomly distributed within each stand. These clipped plots provided an estimate of the coefficient of variation (CV) by vegetation classes and species in each stand. The CV in turn forms the basis for determining the number of plots required to achieve given levels of sampling precision.

The formula used to compute the number of plots (N) needed for the specified levels of sampling accuracy (Freese 1967) shown in table 1 is:

$$N = \frac{(CV)^2 \quad (t)^2}{(SE)^2}$$

where CV = coefficient of variation
SE = desired standard error as proportion of mean
t = "t" table value for desired probability level at estimated number of plots

The coefficient of variation is a measure of plot-to-plot variability (standard deviation) expressed as a percent of the mean. Variability in production between plots is determined primarily by relationship between plot size and the distribution of the plants. For example, this variation is less on a bluegrass pasture than on a scattered bunchgrass range when each is sampled by the same size plots. Although sampling accuracy can usually be improved by increasing plot size, the time required to measure the vegetation also increases as the plots become larger. I have concluded from over a decade of experience on Montana rangelands that a 4.8-ft^2 circular plot is a suitable compromise for measuring herbaceous production on most mountain grassland types. This size agrees with the findings of Van Dyne and others (1963) during their study of the efficiency of plot size and shape for measuring production on a bunchgrass range in southwestern Montana. They found that 4-ft^2 plots were more efficient than either 2- or 6-ft^2 plots and that circular plots were more efficient than either square or rectangular plots.

The more irregularly plants are distributed on an area, the more plots of a given size must be measured to estimate production with the same degree of precision. Overall production on a range type may appear fairly uniform; however, production of individual species and sometimes of vegetation classes is often very irregular. Usually, we must sacrifice some of the desired precision to "getting-the-job-done" in a limited period of time. For example, to achieve sampling precision within ±10 percent of the mean usually requires two to three times as many plots as ±20 percent. Similarly, to be 90 percent confident that the true mean will be within the selected range of the sample mean will often take at least half again as many plots as settling for a confidence level of 80 percent. The 80 percent confidence level appears to be a reasonable

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[2]Mueggler, W. F., and W. P. Handl. 1974. Mountain grassland and shrubland habitat types in western Montana--an interim report. U.S. Forest Service, Intermountain Forest and Range Experiment Station, and Northern Region (Processed) 89 p. Missoula, Montana.

Table 1.--*Range in number of randomly distributed 4.8-ft² plots required to obtain 80 percent probability of achieving sampling accuracy with ±10, ±20, and ±30 percent of the mean production of each population in various habitat types (H.T.). CV is the range in coefficient of variation*

	VEGETATION CLASSES			MAJOR SPECIES		
	Total	Graminoids	Forbs			
STIPA COMATA/BOUTELOUA GRACILIS H.T.						
				Bouteloua gracilis	*Stipa comata*	
CV	0.25-0.38	0.16-0.19	0.49-2.11	0.24	0.64-1.22	
±10%	12-25	6-7	40-730	12	71-244	
±20%	4-7	2-3	11-183	4	19-63	
±30%	3-4	2	6-83	2	9-28	
AGROPYRON SPICATUM/BOUTELOUA GRACILIS H.T.						
				Agropyron spicatum	*Artemisia frigida*	
CV	0.10-0.21	0.20-0.42	0.30-0.36	0.38-0.58	0.58-0.67	
±10%	3-9	8-30	16-23	25-57	56-74	
±20%	2-3	3-8	5-7	7-15	15-20	
±30%	1-2	2-4	3-4	4-8	7-9	
AGROPYRON SPICATUM/A. SMITHII - A. DASYSTACHYUM H.T.						
				Agropyron spicatum		
CV	0.45-0.56	0.55-0.66	0.67-1.43	0.70-1.23		
±10%	34-53	50-74	76-335	81-250		
±20%	10-14	14-19	20-85	21-64		
±30%	5-7	7-9	10-39	10-29		
FESTUCA IDAHOENSIS/A. SMITHII - A. DASYSTACHYUM H.T.						
				Festuca idahoensis	*Agropyron smithii*	
CV	0.13-0.29	0.12-0.34	0.11-0.44	0.33-0.54	0.37-1.03	
±10%	4-15	4-21	3-34	19-50	24-175	
±20%	2-5	2-6	2-9	6-13	7-45	
±30%	2-3	1-4	1-5	3-7	4-21	
FESTUCA IDAHOENSIS/AGROPYRON SPICATUM H.T.						
				Festuca idahoensis	*Agropyron spicatum*	
CV	0.15-0.25	0.10-0.42	0.18-0.75	0.19-1.38	0.54-1.06	
±10%	5-12	2-31	6-93	8-315	49-186	
±20%	2-4	2-9	3-24	3-80	13-48	
±30%	2	1-5	2-12	2-36	7-22	
FESTUCA IDAHOENSIS/AGROPYRON CANINUM H.T.						
				Festuca idahoensis	*Bromus carinatus*	*Lupinus sericeus*
CV	0.18-0.24	0.23-0.37	0.20-0.38	0.39-0.70	1.06-1.17	0.71
±10%	9-11	10-24	8-25	27-83	185-226	85
±20%	3-4	4-7	3-7	8-21	47-58	22
±30%	2	2-4	2-4	4-10	22-26	11

(con.)

Table 1.--(con.)

	VEGETATION CLASSES			MAJOR SPECIES		
	Total	Graminoids	Forbs			
FESTUCA SCABRELLA/AGROPYRON SPICATUM H.T.						
				Festuca scabrella	*Festuca idahoensis*	*Lupinus sericeus*
CV	0.20-0.34	0.27-0.43	0.52-0.71	0.41-0.58	0.48-0.73	0.90-1.78
±10%	8-21	14-32	46-84	29-57	40-88	276-518
±20%	3-6	4-9	12-22	8-15	11-23	70-130
±30%	2-3	3-5	6-11	4-8	6-11	32-59
FESTUCA SCABRELLA/FESTUCA IDAHOENSIS H.T.						
				Festuca scabrella	*Festuca idahoensis*	
CV	0.21-0.45	0.19-0.47	0.64-1.34	0.19-0.71	0.79-0.84	
±10%	9-34	7-38	68-221	7-84	104-116	
±20%	3-10	3-11	18-56	3-22	27-30	
±30%	2-5	2-5	9-26	2-11	13-14	
ARTEMISIA TRIDENTATA/AGROPYRON SPICATUM H.T.						
				Artemisia tridentata	*Agropyron spicatum*	
CV	0.32-0.57	0.33-0.60	0.67-1.25	1.07-1.79	0.50-0.70	
±10%	19-55	19-60	75-255	187-526	42-81	
±20%	6-15	6-16	20-65	48-131	12-21	
±30%	3-7	3-8	9-30	22-60	6-10	
ARTEMISIA TRIDENTATA/FESTUCA IDAHOENSIS H.T.						
				Artemisia tridentata	*Festuca idahoensis*	
CV	0.27-0.57	0.37-0.43	0.35-0.53	0.82-1.74	0.34-0.40	
±10%	13-55	24-31	22-47	113-496	20-28	
±20%	4-15	7-9	6-13	29-124	6-8	
±30%	3-7	4-5	4-6	14-56	3-4	
POTENTILLA FRUTICOSA/FESTUCA SCABRELLA H.T.						
				Potentilla fruticosa	*Festuca scabrella*	
CV	0.15-0.26	0.27-0.28	0.40-0.47	1.73-2.76	0.30-0.77	
±10%	5-13	13-14	28-38	492-1248	16-98	
±20%	2-4	4-5	8-10	124-312	4-25	
±30%	2	3	4-5	56-140	3-12	
PURSHIA TRIDENTATA/FESTUCA SCABRELLA H.T.						
				Purshia tridentata	*Festuca scabrella*	
CV	0.52-0.60	0.41-0.45	0.78-0.86	1.54-3.16	1.23-1.74	
±10%	45-60	28-35	100-124	375-1642	250-500	
±20%	12-16	8-10	26-32	95-411	64-125	
±30%	6-8	4-5	12-15	43-182	29-57	

compromise for much of our range production sampling. Therefore, it is used in table 1 as the probability level for sampling precision levels of ±10, ±20, and ±30 percent of the estimated population mean.

RESULTS AND DISCUSSION

Neither vegetation production nor its distribution over the land surface are uniform between stands within a habitat type classification unit. The differences in areal distribution are reflected by the range in CV values, which in turn dictates sample plot requirements for desired levels of precision (table 1).

Fortunately, on these habitat types, production of the graminoid vegetation class (total grasses and sedges) can be sampled to the same level of precision as total vegetation with a similar number of plots. Forb production, however, usually is more varied and sampling precision will be considerably lower unless more plots are measured. Production of only the most abundant individual species can be sampled to reasonably precise levels within the plot/time constraints usually faced by range examiners. The major grass species are more easily sampled than either the forb or shrub species. An accurate measure of shrub production can involve a seemingly impossible number of 4.8-ft^2 plots. When this situation occurs, some other approach to shrub production should be considered, such as using larger plots designed specifically for the shrubs or reducing accuracy requirements.

The information contained in table 1 merely serves as a guide to sampling requirements for determining forage production. One can easily calculate requirements for a specific area by computing the CV either from data collected in previous years or from a limited number of sample plots. Once the CV is obtained, plot requirements to achieve desired levels of precision can easily be computed by the formula already given.

A range examiner often will not have the time to clip the sometimes large number of plots required to reach desired precision levels. In such cases, either the desired level must be reduced or alternatives to clipping used, such as weight estimates, ranking, or double sampling (Reppert and others 1963). Given the same number of plots, however, all methods of visual estimation introduce greater potential error in determining production on a plot than does actual clipping.

An estimation approach that I have found useful for expanding plot numbers is to rate production on four plots with reference to production on a central clipped plot. The four rated and one clipped plot constitute a set. The number of randomly distributed sets used is determined by the level of precision desired. The five plots within a set are located within easy view of one another so that production on each rated plot can easily be estimated as a percent of that on the plot to be clipped. Total production, production by vegetation classes, and by major species, if desired, are estimated as a percent of that produced on the plot that will be clipped. Following clipping and weighing by the selected categories, the percentage figures for each rated plot are converted to weight. Thus, production values for five plots can be obtained by clipping only one. Of course, measurement error will be greater on the rated than on the clipped plots. But, this disadvantage is also true for estimating weight by weight units. Rating in percent, however, circumvents the disadvantage of establishing and mentally maintaining the weight units required for weight estimates.

Regardless of the method used to obtain herbage production, the range examiner should be aware of the probable accuracy of his data. Preferably, he should compute the statistical confidence limits of his data, bearing in mind the possible error involved in plot measurements. Then he would be in a position to tailor his conclusions regarding production to the precision level of his data.

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FOREST AREA AND TIMBER VOLUME STATISTICS FOR WESTERN SOUTH DAKOTA, 1974

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ABSTRACT

Presents land area classifications by Forest and Range Resources Evaluation standards and timber volume data by species, forest type, stand-size class, and ownership.

OXFORD: 524.61, 524.3
KEYWORDS: forest surveys (regional), stand volume, forest area classification

Data presented here are based on comprehensive timber surveys made in South Dakota west of the 103rd meridian from 1971 through 1974 by the South Dakota State Department of Game, Fish, and Parks, Division of Forestry; and the Rocky Mountain Region of the Forest Service in cooperation with the Intermountain Forest and Range Experiment Station.

This Note provides the basic timber resource information in tabular form (tables 1-11) and a brief discussion of the data and terminology. A more comprehensive, descriptive, and analytical report on the timber resources of western South Dakota is being prepared.

FOREST AREA AND OWNERSHIP

Approximately 20 percent of the total land area (fig. 1) in western South Dakota is forested (table 1). Pennington, Custer, and Lawrence Counties (in order) have the highest proportion of land area occupied by productive forests.

Only 1 percent of the productive forest land is reserved from timber cutting. This reserved area includes Mt. Rushmore, Wind Cave, and Jewel Cave National Parks and a small portion of the Black Hills National Forest.

Over 80 percent of the productive nonreserved forest land is publicly owned; the Forest Service administers most of it. Most of the unproductive forest land is privately owned.

[1]Respectively, Assistant Resource Analyst, Computer Programer, and Resource Analyst.

Figure 1.--Location of sample area in western South Dakota.

Table 1.--*Land area by county and major land class, western South Dakota, 1974*

County	FOREST LAND: Productive: Nonreserved	Productive: Reserved	Unproductive: Nonreserved	Unproductive: Reserved	Total	Nonforest land[1]	Total land area[2]
	Thousand acres[3]						
Butte	4.9	--	7.4	--	12.3	1,427.4	1,439.7
Custer[4]	359.9	10.0	25.9	.2	396.0	483.3	879.3
Fall River	57.3	--	35.8	--	93.1	1,022.5	1,115.6
Harding	16.3	--	4.0	--	20.3	1,696.2	1,716.5
Lawrence	332.7	--	16.9	--	349.6	162.4	512.0
Meade[4]	61.4	--	9.0	--	70.4	485.8	556.2
Pennington[4]	406.5	1.1	8.8	1.1	417.5	242.0	659.5
Total	1,239.0	11.1	107.8	1.3	1,359.2	5,519.6	6,878.8

[1]Includes 8,300 acres classed as water by Forest and Range Resources Evaluation standards, but defined as land by the Bureau of the Census.
[2]U.S. Bureau of the Census, land and water area of the United States, 1970.
[3]Acres can be converted to hectares by dividing acres by 2.471. Cubic feet shown in later tables can be converted to cubic meters by dividing cubic feet by 35.31.
[4]This and later tables include only the portions of these counties west of the 103rd meridian.

VOLUME

The 1.2 million acres of productive forest land (nonreserved) contain about 1.6 billion cubic feet (5.6 billion board feet) of standing timber. Nearly all of the area is the ponderosa pine (*Pinus ponderosa*) type and about two-thirds of it is sawtimber stands.

DATA RELIABILITY

The data presented here all meet or exceed national Forest and Range Resources Evaluation accuracy standards with sampling errors of ±3 percent per million acres of productive nonreserved forest land area, ±10 percent per million acres of unproductive nonreserved forest land area, and ±10 percent per billion cubic feet of growing stock volume. These standards are in terms of one standard error--the 67 percent confidence level. Cells within tables should be used with caution, because some may be based upon small sample sizes, thus resulting in very high sampling errors.

On non-National Forest lands, forest land area and timber volume were estimated from a stratified double sample design using points on resource aerial photography for the primary sample, and ground plots for the secondary sample. Sampling error estimates for the actual area samples (reserved lands excluded) are:

	Percent
Productive forest area	±2.18
Unproductive forest area	±6.38
Total cubic-foot volume	±3.35
Total board-foot volume	±4.15

The Black Hills and Custer National Forests, sampled as separate entities, are not entirely included within the area reported so actual sampling errors are not available. However, individual National Forest accuracy requirements usually greatly exceed national minimum requirements. The sampling design used for these National Forests is generally similar to that used for the other lands in western South Dakota.

TERMINOLOGY

Forest type.--A classification of forest land based upon the species forming a plurality of live-tree stocking.

MAJOR LAND CLASSES:

Productive forest land.--Forest land producing or capable of producing crops of industrial wood (minimum 20 cubic feet per acre per year). However, some of this land may not be available for timber production, depending upon owner intent.

Unproductive forest land.--Forest land that is not capable of producing crops of industrial wood because of adverse site conditions.

Nonforest land.--Land that has never supported forests, and lands formerly forested where timber utilization is precluded by development for other uses.

Reserved forest land.--Forest land withdrawn from use for timber utilization because of statute or administrative regulation.

STAND-SIZE CLASSES:

Sawtimber stands.--Stands at least 16.7 percent stocked with growing stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

Poletimber stands.--Stands at least 16.7 percent stocked with growing stock trees in which half or more is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

Sapling/seedling stands.--Stands at least 16.7 percent stocked with growing stock trees in which more than half the stocking is sapling and/or seedling.

Nonstocked areas.--Productive forest land less than 16.7 percent stocked with growing stock trees.

TREE SIZE CLASSES:

Seedlings.--Live trees less than 1.0 inch diameter breast height.

Saplings.--Trees 1.0 to 5.0 inches diameter breast height.

Poletimber trees.--Trees at least 5.0 inches diameter, but smaller than sawtimber size.

Sawtimber trees.--Trees at least 9.0 inches diameter breast height for softwoods and 11.0 inches diameter breast height for hardwoods.

CLASS OF TIMBER:

Growing stock trees.--All live noncull trees at least 5.0 inches diameter breast height.

VOLUME:

Net volume.--Gross volume less deductions for rot, sweep, or other defects affecting use for timber products.

Growing stock volume.--Net volume in cubic feet of live growing stock sawtimber trees and live poletimber trees from stump to a minimum 4.0-inch diameter top outside bark.

Sawtimber volume.--Net volume in International 1/4-inch rule board feet of live growing stock sawtimber trees.

OWNER CLASSES:

Ownership.--Property owned by one owner, regardless of the number of parcels in a specified area.

National Forest land.--Federal lands which have been legally designated as National Forest or purchase units, and other lands under the administration of the Forest Service including experimental areas and Bankhead-Jones Title III lands.

Other public.--Lands owned by States, counties, local public agencies or municipalities, or lands leased to these governmental units for 50 years or more; all Federal lands other than National Forest lands; tribal lands held in fee by the Federal Government, but administered for Indian tribal groups, and Indian trust allotments.

Private.--Lands not owned or administered by public agencies.

Table 2.--*Area of productive nonreserved forest land by county, forest type, and stand-size class, western South Dakota, 1974*

County	Forest type	STAND-SIZE CLASS: Sawtimber	Poletimber	Sapling/seedling	Nonstocked	Total
		Thousand acres				
Butte	Ponderosa pine	2.6	1.0	.2	--	3.8
	Spruce-fir	--	--	--	--	--
	Hardwoods	.9	.2	--	--	1.1
	Total	3.5	1.2	.2	--	4.9
Custer	Ponderosa pine	235.5	82.7	35.4	1.6	355.2
	Spruce-fir	3.6	--	--	--	3.6
	Hardwoods	.9	.1	.1	--	1.1
	Total	240.0	82.8	35.5	1.6	359.9
Fall River	Ponderosa pine	30.7	13.0	8.5	4.9	57.1
	Spruce-fir	.2	--	--	--	.2
	Hardwoods	--	--	--	--	--
	Total	30.9	13.0	8.5	4.9	57.3
Harding	Ponderosa pine	7.7	5.4	2.1	([1])	15.2
	Spruce-fir	--	--	--	--	--
	Hardwoods	.8	.2	.1	--	1.1
	Total	8.5	5.6	2.2	([1])	16.3
Lawrence	Ponderosa pine	204.6	67.0	13.1	1.2	285.9
	Spruce-fir	12.7	--	--	--	12.7
	Hardwoods	25.8	4.1	4.2	--	34.1
	Total	243.1	71.1	17.3	1.2	332.7
Meade	Ponderosa pine	30.7	21.2	3.7	.1	55.7
	Spruce-fir	.3	--	--	--	.3
	Hardwoods	3.9	.9	.6	--	5.4
	Total	34.9	22.1	4.3	.1	61.4
Pennington	Ponderosa pine	268.4	106.4	17.1	.7	392.6
	Spruce-fir	7.4	--	--	--	7.4
	Hardwoods	4.5	1.4	.6	--	6.5
	Total	280.3	107.8	17.7	.7	406.5
All counties	Ponderosa pine	780.2	296.7	80.1	8.5	1,165.5
	Spruce-fir	24.2	--	--	--	24.2
	Hardwoods	36.8	6.9	5.6	--	49.3
	Total	841.2	303.6	85.7	8.5	1,239.0

[1] Less than 50 acres.

Table 3.--*Area of productive nonreserved forest land by county, ownership class, and forest type, western South Dakota, 1974*

County	Ownership class	FOREST TYPE: Ponderosa pine	Spruce-fir	Hardwood	Total
		Thousand acres			
Butte	Natl. Forest	--	--	--	--
	Other public	--	--	([1])	([1])
	Private	3.8	--	1.1	4.9
	Total	3.8	--	1.1	4.9
Custer	Natl. Forest	255.9	3.6	.5	260.0
	Other public	56.5	--	.1	56.6
	Private	42.8	--	.5	43.3
	Total	355.2	3.6	1.1	359.9
Fall River	Natl. Forest	19.1	.2	--	19.3
	Other public	3.8	--	--	3.8
	Private	34.2	--	--	34.2
	Total	57.1	.2	--	57.3
Harding	Natl. Forest	10.4	--	--	10.4
	Other public	3.7	--	.8	4.5
	Private	1.1	--	.3	1.4
	Total	15.2	--	1.1	16.3
Lawrence	Natl. Forest	238.1	7.3	11.7	257.1
	Other public	6.3	.7	2.6	9.6
	Private	41.5	4.7	19.8	66.0
	Total	285.9	12.7	34.1	332.7
Meade	Natl. Forest	32.5	.3	.7	33.5
	Other public	1.5	--	.3	1.8
	Private	21.7	--	4.4	26.1
	Total	55.7	.3	5.4	61.4
Pennington	Natl. Forest	351.0	6.9	6.5	364.4
	Other public	2.6	([1])	--	2.6
	Private	39.0	.5	--	39.5
	Total	392.6	7.4	6.5	406.5
All counties	Natl. Forest	907.0	18.3	19.4	944.7
	Other public	74.4	.7	3.8	78.9
	Private	184.1	5.2	26.1	215.4
	Total	1,165.5	24.2	49.3	1,239.0

[1] Less than 50 acres.

Table 4.--*Area of productive nonreserved forest land by county, ownership class, and stand-size class, western South Dakota, 1974*

County	Ownership class	Sawtimber	Poletimber	Sapling/ seedling	Nonstocked	Total
		STAND-SIZE CLASS				
		Thousand acres				
Butte	Natl. Forest	--	--	--	--	--
	Other public	(1)	--	--	--	(1)
	Private	3.5	1.2	.2	--	4.9
	Total	3.5	1.2	.2	--	4.9
Custer	Natl. Forest	185.7	64.9	9.4	(1)	260.0
	Other public	36.0	6.6	12.9	1.1	56.6
	Private	18.3	11.3	13.2	.5	43.3
	Total	240.0	82.8	35.5	1.6	359.9
Fall River	Natl. Forest	13.2	5.5	.6	--	19.3
	Other public	1.8	.7	.8	.5	3.8
	Private	15.9	6.8	7.1	4.4	34.2
	Total	30.9	13.0	8.5	4.9	57.3
Harding	Natl. Forest	5.2	3.5	1.7	(1)	10.4
	Other public	2.4	1.7	.4	--	4.5
	Private	.9	.4	.1	--	1.4
	Total	8.5	5.6	2.2	(1)	16.3
Lawrence	Natl. Forest	185.2	60.5	10.2	1.2	257.1
	Other public	7.3	1.4	.9	--	9.6
	Private	50.6	9.2	6.2	--	66.0
	Total	243.1	71.1	17.3	1.2	332.7
Meade	Natl. Forest	20.9	11.0	1.5	.1	33.5
	Other public	.8	.8	.2	--	1.8
	Private	13.2	10.3	2.6	--	26.1
	Total	34.9	22.1	4.3	.1	61.4
Pennington	Natl. Forest	259.1	90.9	13.7	.7	364.4
	Other public	1.2	1.2	.2	--	2.6
	Private	20.0	15.7	3.8	--	39.5
	Total	280.3	107.8	17.7	.7	406.5
All counties	Natl. Forest	669.3	236.3	37.1	2.0	944.7
	Other public	49.5	12.4	15.4	1.6	78.9
	Private	122.4	54.9	33.2	4.9	215.4
	Total	841.2	303.6	85.7	8.5	1,239.0

[1]Less than 50 acres.

Table 5.--*Area of productive reserved and unproductive reserved and nonreserved forest land by county, ownership class, and forest type, western South Dakota, 1974*

County	Ownership class	FOREST TYPE: Ponderosa pine	Spruce-fir	Other softwoods	Hardwood	Total
		- - - - - - - - - Thousand acres - - - - - - - - -				
Butte	Natl. Forest	--	--	--	--	--
	Other public	--	--	--	.3	.3
	Private	.8	--	.4	5.9	7.1
	Total	.8	--	.4	6.2	7.4
Custer	Natl. Forest	10.7	--	--	--	10.7
	Other public	10.3	.2	.1	.1	10.7
	Private	10.4	--	2.1	2.2	14.7
	Total	31.4	.2	2.2	2.3	36.1
Fall River	Natl. Forest	8.7	--	--	--	8.7
	Other public	2.0	--	.2	.4	2.6
	Private	18.0	--	2.5	4.0	24.5
	Total	28.7	--	2.7	4.4	35.8
Harding	Natl. Forest	1.3	--	--	--	1.3
	Other public	.5	--	.3	.6	1.4
	Private	.2	--	.1	1.0	1.3
	Total	2.0	--	.4	1.6	4.0
Lawrence	Natl. Forest	3.2	--	--	--	3.2
	Other public	.3	--	.1	.9	1.3
	Private	2.6	--	.9	8.9	12.4
	Total	6.1	--	1.0	9.8	16.9
Meade	Natl. Forest	.4	--	--	--	.4
	Other public	.1	--	--	.3	.4
	Private	1.3	--	1.5	5.4	8.2
	Total	1.8	--	1.5	5.7	9.0
Pennington	Natl. Forest	5.7	--	--	--	5.7
	Other public	1.0	--	--	.6	1.6
	Private	.4	--	--	3.3	3.7
	Total	7.1	--	--	3.9	11.0
All counties	Natl. Forest	30.0	--	--	--	30.0
	Other public	14.2	.2	.7	3.2	18.3
	Private	33.7	--	7.5	30.7	71.9
	Total	77.9	.2	8.2	33.9	120.2

Table 6.--*Net volume of growing stock on productive nonreserved forest land by county and species, western South Dakota, 1974*

County	SOFTWOODS			HARDWOODS				Total all species
	Ponderosa pine	White spruce[1]	Total softwoods	Aspen	Cottonwood	Other hardwoods	Total hardwoods	
	Thousand cubic feet							
Butte	3,049	--	3,049	7	572	220	799	3,848
Custer	423,651	9,933	433,584	734	--	666	1,400	434,984
Fall River	40,502	527	41,029	33	--	72	105	41,134
Harding	5,971	--	5,971	6	71	170	247	6,218
Lawrence	448,895	30,626	479,521	5,082	--	3,499	8,581	488,102
Meade	70,900	970	71,870	188	405	862	1,455	73,325
Pennington	561,666	19,081	580,747	2,285	--	1,345	3,630	584,377
All counties	1,554,634	61,137	1,615,771	8,335	1,048	6,834	16,217	1,631,988

[1]May include Engelmann spruce.

Table 7.--*Net volume of sawtimber on productive nonreserved forest land by county and species, western South Dakota, 1974*

County	SOFTWOODS			HARDWOODS				Total all species
	Ponderosa pine	White spruce[1]	Total softwoods	Aspen	Cottonwood	Other hardwoods	Total hardwoods	
	Thousand board feet[2]							
Butte	9,531	--	9,531	--	2,930	592	3,522	13,053
Custer	1,450,097	43,730	1,493,827	18	--	465	483	1,494,310
Fall River	120,182	2,205	122,387	--	--	206	206	122,593
Harding	14,115	--	14,115	--	365	327	692	14,807
Lawrence	1,593,241	122,614	1,715,855	920	--	5,594	6,514	1,722,369
Meade	213,127	3,994	217,121	12	2,078	1,421	3,511	220,632
Pennington	1,900,458	84,772	1,985,230	505	--	2,847	3,352	1,988,582
All counties	5,300,751	257,315	5,558,066	1,455	5,373	11,452	18,280	5,576,346

[1]May include Engelmann Spruce.

[2]International 1/4-inch rule.

Table 8.--*Net volume of growing stock on productive nonreserved forest land by county, forest type, and stand-size class, western South Dakota, 1974*

County	Forest type	STAND-SIZE CLASS: Sawtimber	Poletimber	Sapling/ seedling	Nonstocked	Total
		- - - - - - - - - - *Thousand cubic feet* - - - - - - - - - -				
Butte	Ponderosa pine	2,166	504	40	--	2,710
	Spruce-fir	--	--	--	--	--
	Hardwoods	1,049	89	--	--	1,138
	Total	3,215	593	40	--	3,848
Custer	Ponderosa pine	334,305	79,962	11,652	276	426,195
	Spruce-fir	8,144	--	--	--	8,144
	Hardwoods	613	26	6	--	645
	Total	343,062	79,988	11,658	276	434,984
Fall River	Ponderosa pine	27,731	9,671	2,986	310	40,698
	Spruce-fir	436	--	--	--	436
	Hardwoods	--	--	--	--	--
	Total	28,167	9,671	2,986	310	41,134
Harding	Ponderosa pine	3,487	1,363	607	--	5,457
	Spruce-fir	--	--	--	--	--
	Hardwoods	562	180	19	--	761
	Total	4,049	1,543	626	--	6,218
Lawrence	Ponderosa pine	351,649	79,651	1,712	--	433,012
	Spruce-fir	25,617	--	--	--	25,617
	Hardwoods	26,189	1,960	1,324		29,473
	Total	403,455	81,611	3,036	--	488,102
Meade	Ponderosa pine	47,021	20,694	752	--	68,467
	Spruce-fir	613	--	--	--	613
	Hardwoods	3,074	1,013	158	--	4,245
	Total	50,708	21,707	910	--	73,325
Pennington	Ponderosa pine	444,689	117,552	3,463	--	565,704
	Spruce-fir	15,547	--	--	--	15,547
	Hardwoods	2,628	412	86	--	3,126
	Total	462,864	117,964	3,549	--	584,377
All counties	Ponderosa pine	1,211,048	309,397	21,212	586	1,542,243
	Spruce-fir	50,357	--	--	--	50,357
	Hardwoods	34,115	3,680	1,593	--	39,388
	Total	1,295,520	313,077	22,805	586	1,631,988

Table 9.--*Net volume of sawtimber on productive nonreserved forest land by county, forest type, and stand-size class, western South Dakota, 1974*

County	Forest type	STAND-SIZE CLASS: Sawtimber	Poletimber	Sapling/seedling	Nonstocked	Total
		Thousand board feet[1]				
Butte	Ponderosa pine	7,510	734	78	--	8,322
	Spruce-fir	--	--	--	--	--
	Hardwoods	4,510	221	--	--	4,731
	Total	12,020	955	78	--	13,053
Custer	Ponderosa pine	1,271,289	139,360	40,402	700	1,451,751
	Spruce-fir	39,878	--	--	--	39,878
	Hardwoods	2,660	11	10	--	2,681
	Total	1,313,827	139,371	40,412	700	1,494,310
Fall River	Ponderosa pine	95,595	15,659	8,884	554	120,692
	Spruce-fir	1,901	--	--	--	1,901
	Hardwoods	--	--	--	--	--
	Total	97,496	15,659	8,884	554	122,593
Harding	Ponderosa pine	9,598	1,971	926	--	12,495
	Spruce-fir	--	--	--	--	--
	Hardwoods	1,912	374	26	--	2,312
	Total	11,510	2,345	952	--	14,807
Lawrence	Ponderosa pine	1,368,473	136,861	5,328	--	1,510,662
	Spruce-fir	109,547	--	--	--	109,547
	Hardwoods	97,431	1,349	3,380	--	102,160
	Total	1,575,451	138,210	8,708	--	1,722,369
Meade	Ponderosa pine	170,944	33,101	1,202	--	205,247
	Spruce-fir	2,852	--	--	--	2,852
	Hardwoods	10,477	1,834	222	--	12,533
	Total	184,273	34,935	1,424	--	220,632
Pennington	Ponderosa pine	1,692,695	201,813	9,245	--	1,903,753
	Spruce-fir	75,995	--	--	--	75,995
	Hardwoods	8,521	168	145	--	8,834
	Total	1,777,211	201,981	9,390	--	1,988,582
All counties	Ponderosa pine	4,616,104	529,499	66,065	1,254	5,212,922
	Spruce-fir	230,173	--	--	--	230,173
	Hardwoods	125,511	3,957	3,783	--	133,251
	Total	4,971,788	533,456	69,848	1,254	5,576,346

[1]International 1/4-inch rule.

Table 10.--*Net volume of growing stock on productive nonreserved forest land by county and ownership class, western South Dakota, 1974*

County	OWNERSHIP CLASS			
	National Forest	Other public	Private	Total all owners
	Thousand cubic feet			
Butte	--	41	3,807	3,848
Custer	353,504	56,226	25,254	434,984
Fall River	22,941	1,818	16,375	41,134
Harding	2,000	3,214	1,004	6,218
Lawrence	376,998	14,187	96,917	488,102
Meade	50,781	1,376	21,168	73,325
Pennington	536,571	2,799	45,007	584,377
All counties	1,342,795	79,661	209,532	1,631,988

Table 11.--*Net volume of sawtimber on productive nonreserved forest land by county and ownership class, western South Dakota, 1974*

County	OWNERSHIP CLASS			
	National Forest	Other public	Private	Total all owners
	Thousand board feet[1]			
Butte	--	197	12,856	13,053
Custer	1,231,557	197,343	65,410	1,494,310
Fall River	73,844	5,000	43,749	122,593
Harding	3,069	8,601	3,137	14,807
Lawrence	1,329,627	49,132	343,610	1,722,369
Meade	158,816	3,498	58,318	220,632
Pennington	1,862,179	6,951	119,452	1,988,582
All counties	4,659,092	270,722	646,532	5,576,346

[1]International 1/4-inch rule.

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1976

OPTIMUM EGG GALLERY DENSITIES FOR THE MOUNTAIN PINE BEETLE IN RELATION TO LODGEPOLE PINE PHLOEM THICKNESS[1]

Gene D. Amman and Vincent E. Pace[2]

ABSTRACT

*Laboratory studies were conducted to determine optimum densities of egg galleries constructed by the mountain pine beetle (*Dendroctonus ponderosae *Hopkins) in lodgepole pine (*Pinus contorta *var.* latifolia *Engelmann) phloem of different thickness. Beetle production per unit area of lodgepole pine bark occurred at egg gallery densities over 2.4 m per 30.4 cm² with greater production obtained from thick phloem. Beetle production began to flatten at about 2.1 m per 30.4 cm² in thin phloem and at 2.4 m in thick phloem. Production curves remained asymptotic to 3 m of egg gallery per 30.4 cm² the upper limit observed in this study. Beetle production per unit of egg gallery length was highest at the lowest gallery density in all phloem thicknesses. As expected, beetle production was greatest in thick phloem.*

The largest brood adults emerged from thick phloem at all egg gallery densities. But, for thick and thin phloem alike, size declined after egg gallery densities exceeded about 1.5 m per 30.4 cm². Beetles were significantly smaller in thin phloem, even at the lowest gallery densities. Male survival was proportionately lower in thin phloem than in thick phloem. The smaller size of beetles and lower survival of males suggest a qualitative difference between thin and thick phloem that may be important in dynamics of mountain pine beetle populations.

OXFORD: 811.71
KEYWORDS: *Dendroctonus ponderosae*, *Pinus contorta*, phloem, bark beetle, beetle production, gallery density

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Several authors have conducted studies of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) brood production and survival in lodgepole pine (*Pinus contorta* var. *latifolia* Engelmann) in relation to egg gallery or attack densities. Cole (1962) found that production per inch of gallery was greatly reduced at high attack densities in the laboratory. Reid (1963) reported that a similar relation existed in the field.

Both studies were made prior to the discovery of the importance of phloem thickness to brood production of the mountain pine beetle (Amman 1972a). Consequently, the purpose of this study was to determine optimum egg gallery densities for beetle production and beetle size in relation to phloem thickness. Data presented here should be useful in developing future models of mountain pine beetle production that incorporate food quantity coefficients such as those proposed by Berryman (1974).

MATERIAL AND METHODS

Four uninfested and four infested lodgepole pine trees were felled on the Wasatch National Forest south of Evanston, Wyoming, in November 1973. Billets 50 cm long were cut from each tree and the ends waxed to slow moisture loss. The billets then were taken to our laboratory in Ogden, Utah. Uninfested billets were stored at 2°C. Infested billets were kept at room temperatures of 19°-22°C so immature beetles could complete development and emerge.

In January 1974, 20 areas (15.2 cm wide by 30.4 cm high) were delineated on uninfested billets in each of four phloem thickness classes.

Phloem class	*Mean*	*SD*
	- - - - - - *mm* - - - - -	
1	1.8	0.28
2	2.7	.23
3	3.8	.28
4	4.8	.23

A 2.5-cm strip of bark was removed around the perimeter of each of the 80 areas. Exposed sapwood and bark edges were waxed to slow moisture loss.

Vertical holes (5 mm in diameter and 2.5 cm deep) were drilled in the bark along the lower 15.2 cm edge of each area. One pair of beetles was introduced into each hole. Sex of beetles was determined by characteristics of the seventh abdominal tergum (Lyon 1958). The number of holes per area varied from one to five, depending upon desired attack density. Each attack density was replicated four times in each phloem thickness.

The newly infested billets were kept upright at room temperatures of 22°-26°C and humidity of 20-40 percent throughout the experiment. Plastic screen cages (32 by 32 mesh) were placed over each infested area and stapled to the sapwood. Plastic test tubes served to catch emerging beetles. Beetles were collected, counted, and sexed daily. Length was measured with an ocular micrometer in a dissecting microscope. After emergence was completed, bark was peeled from each of the 80 areas. Remaining beetles, meters of egg gallery, and successful attacks were counted.

Beetle production per unit area of bark.--Beetle production for similar gallery densities did not differ significantly ($P > 0.10$) between phloem thickness classes 1 and 2, nor between phloem thickness classes 3 and 4. Production between combined phloem classes 1 and 2 and that from combined 3 and 4 differed significantly, ($P < 0.005$). Consequently, the final model involved two regressions (fig. 1). Although the overall model is significant, the coefficient of determination is relatively low ($R^2 = 0.38$).

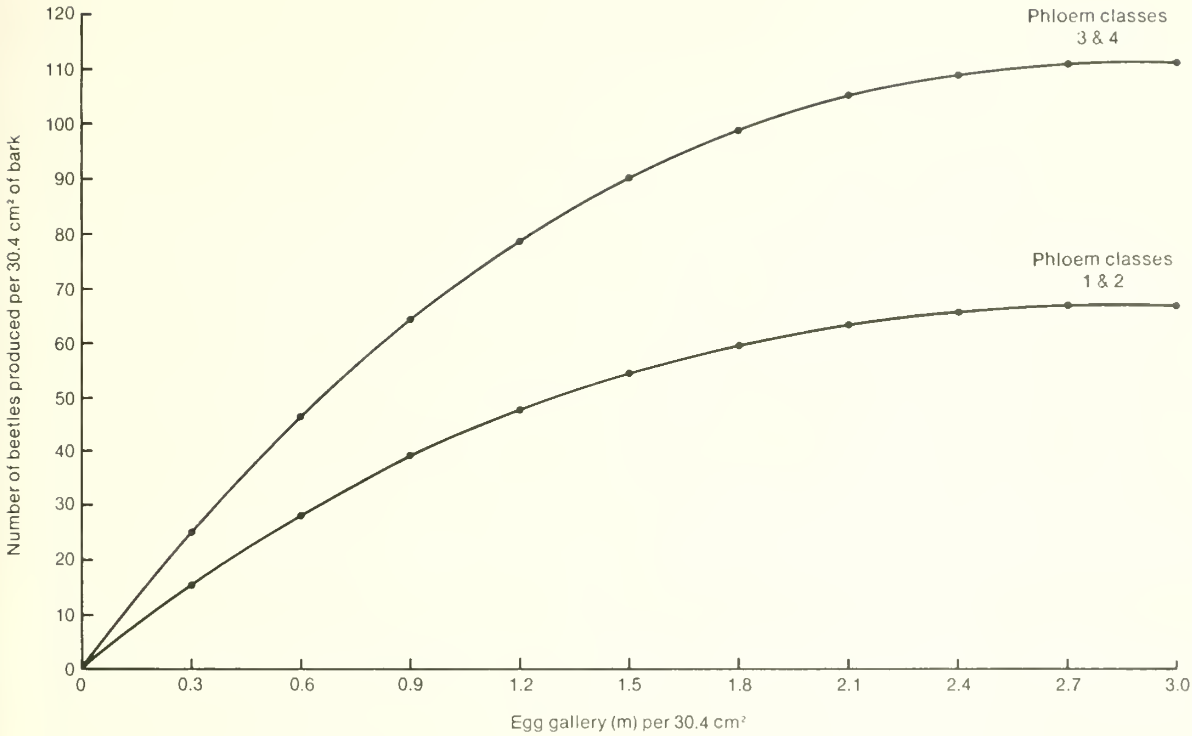

Figure 1.--Mountain pine beetle production per unit area of bark in relation to egg gallery density for two phloem thickness categories. Phloem classes 1 and 2 and phloem classes 3 and 4 were combined because they did not differ significantly.

Phloem classes 1 and 2: $\hat{Y} = 67.262 - 4.816(3-X)^{2.4}$

$S_{y \cdot x} = 25.3$

Phloem classes 3 and 4: $\hat{Y} = 111.247 - 7.965(3-X)^{2.4}$

$S_{y \cdot x} = 34.5$

Limits: $0 \leq x \leq 3$

Production of beetles per unit area of bark followed previously reported expectations (Amman 1972a); the thickest phloem yielded the most beetles at all egg gallery densities. Beetle larvae have more food and space in thick phloem than in thin phloem. Consequently, neither starvation nor encounters between larvae that result in entomocide (one larva killing another) occur as frequently in thick phloem as in thin.

A decline in beetle production with increased gallery density was expected. However, the relation began to flatten at about 2.4 m of egg gallery per 30 cm^2 of bark. Gallery density was optimal between 2.3 and 2.7 m in Reid's (1963) field study. That the numbers of beetles per unit area of bark failed to decline at high egg gallery densities in the laboratory suggests (1) that the maximum number of beetles that can develop and emerge is reached at these levels and (2) that this number probably would remain constant at higher egg gallery densities than occurred in our study.

The shapes of curves for beetle production in relation to egg gallery density in this study differ from those of figure 2 in Amman (1972a). Amman (1972a) did not

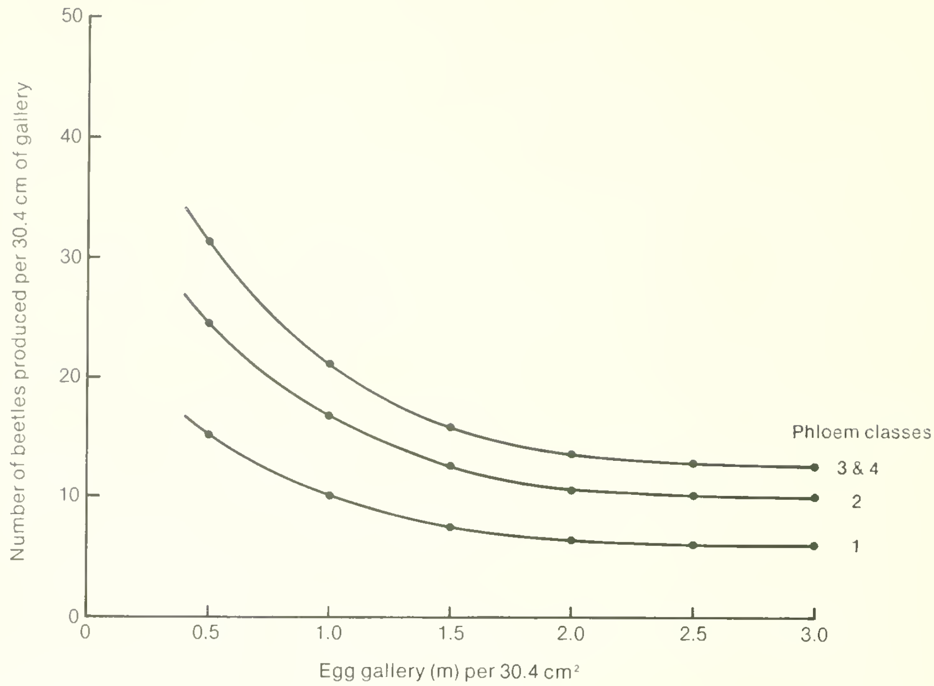

Figure 2.--Mountain pine beetle production per unit length of egg gallery for three phloem thickness categories:

Phloem class 1: $\hat{Y} = 6.157 + 0.3597(3-X)^{3.5}$

$S_{y \cdot x} = 8.4$

Phloem class 2: $\hat{Y} = 10.0492 + 0.5870(3-X)^{3.5}$

$S_{y \cdot x} = 6.6$

Phloem classes 3 and 4: $\hat{Y} = 12.755 + 0.745(3-X)^{3.5}$

$S_{y \cdot x} = 8.6$

Limits: $0.4 \leq x \leq 3$

demonstrate an asymptotic relationship. Phloem in the 1972 study was thicker overall, ranging between 4.1 and 6.6 mm, and apparently was underutilized even at the highest gallery density (4.6 m per 30.4 cm^2). This last is evident from the curve that continues to rise. An asymptotic relation would be expected at higher egg gallery densities.

The apparent asymptotic relation in the present study indicates that the upper limit to beetle numbers is governed by the absolute amount of food. Beetle production per cm^3 of phloem was similar for all phloem thicknesses; the regression was not significantly different from zero ($P > 0.10$).

Although a constant beetle production occurred above about 2.4 m of egg gallery per 30.4 cm^2 in the laboratory, a decline in production occurred in the field when gallery densities exceeded about 2 m in small diameter trees, which usually have thin phloem, and about 3 m per 30.4 cm^2 in large diameter trees, which usually have thick phloem (Cole and others, 1976). Declines in the field indicate that beetle production at high gallery densities is reduced by some factor (s) other than competition. Drying is the most plausible factor.

Cole (1974, 1975) evaluated several mortality factors that were affecting a beetle population in the field. He concluded that no individual mortality factor that he studied--parasites, predators, temperature, crowding (competition), and all unknown factors--offered regulator influence on mountain pine beetle populations. However, he (Cole 1975) observed that cold winter temperatures accompanied by drying of the phloem significantly reduced beetle survival. He reported that beetles survived better in large trees, even when phloem in these trees was thin. This observation is another indication that drying may account for some of the difference in brood production between small- and large-diameter trees having similar phloem thickness.

Cole and others (1976) discussed the decline in field populations as gallery densities increased over time. They stressed that drying of phloem was an important mortality factor of developing brood at high egg gallery densities. The large amount of egg gallery that was constructed when attack densities were high promoted drying of the phloem. Drying also was intensified by large number of feeding larvae that depleted the available phloem. Consequently, drying becomes more important to beetle survival over time as attack and gallery densities increase.

Beetle production per unit length of egg gallery.--Beetle production per unit length of egg gallery was significantly different ($P < 0.05$) among phloem thickness classes (fig. 2). Phloem classes 3 and 4 were combined because they did not differ significantly ($P > 0.10$). The coefficient of determination for this model was relatively low ($R^2 = 0.31$); however, the model is significant ($P < 0.005$).

Survival per unit of egg gallery was highest at the lowest gallery density in all phloem thicknesses (fig. 2). This is not surprising since at this density physical encounters between developing larvae are low. With increased density, larvae from adjacent egg galleries are more likely to come in contact and losses to entomocide and to cannibalism can be expected to increase.

Our data suggest that, on the average, the minimum attack or egg gallery density in the field that will kill a tree or a large area of bark in a strip attack is also the density that will yield the greatest beetle survival from egg to emerged adult. An attack density below the minimum needed to kill the tree or a strip of bark results in galleries becoming impregnated with resin (resinosus) as observed in the field by Reid and others (1967) and failure of resin-enveloped eggs to hatch as demonstrated experimentally by Reid and Gates (1970).

Although the greatest production per unit length of egg gallery occurred at the lowest egg gallery density (fig. 2), the optimum density for maximum beetle production per unit area of bark occurred at high egg gallery densities (fig. 1). An aggressive bark beetle, such as the mountain pine beetle, infests scattered and temporary habitats (Atkins 1966), particularly during endemic periods when the best trees for brood production may be in short supply. Such trees usually are of large diameter and thick phloem. Mountain pine beetles have probably evolved behavior to make the most of a limited food supply furnished by any tree that is infested. Consequently, egg gallery density at which maximum beetle production per unit length of gallery occurs probably would never coincide with egg gallery densities at which maximum beetle production occurs in any phloem thickness. In addition, attacks and egg galleries must be sufficient to prevent complete loss of brood by resinosus.

Beetle size.--Length of female beetles did not differ significantly between phloem thickness classes 1 and 2 nor between phloem classes 3 and 4 ($P > 0.10$). However, the lengths of females from combined groups 1 and 2 differed significantly from combined 3 and 4 ($P < 0.005$) (fig. 3). The coefficient of determination was relatively low ($R^2 = 0.30$); however, the overall model was significant ($P < 0.005$).

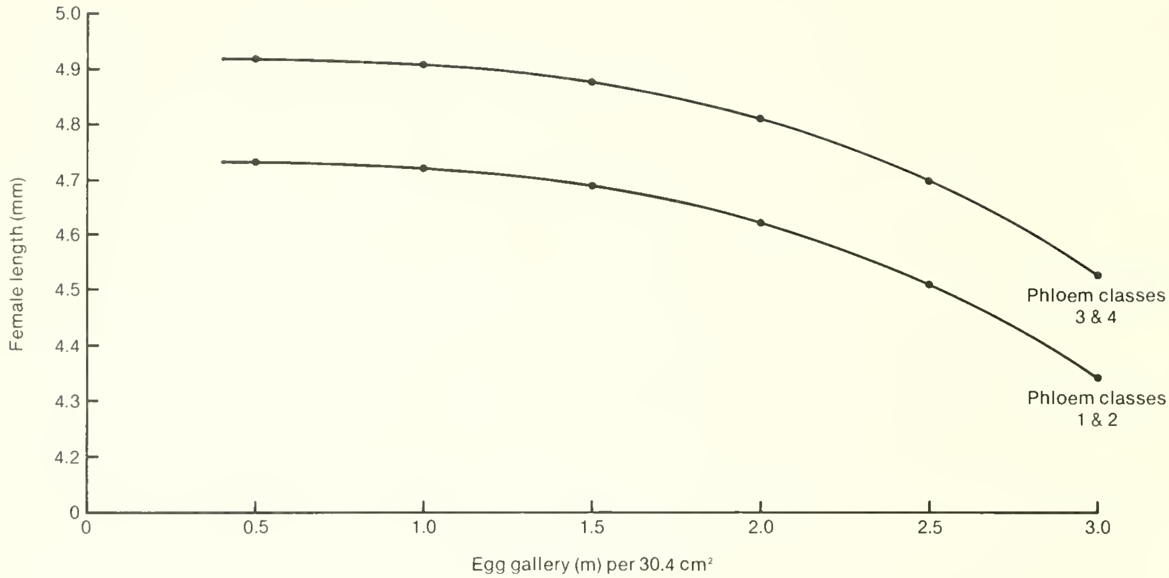

Figure 3.--Length of mountain pine beetle females in relation to egg gallery density for two phloem thickness categories. Phloem classes 1 and 2 and phloem classes 3 and 4 were combined because they did not differ significantly.

Phloem classes 1 and 2: $\hat{Y} = 4.769 - 0.0146X^3$
$S_{y \cdot x} = 0.21$

Phloem classes 3 and 4: $\hat{Y} = 5.006 - 0.0146X^3$
$S_{y \cdot x} = 0.19$

Limits: $0.4 \leq x \leq 3$

Optimum gallery density at which maximum beetle size occurred ranged between 0.4 and 1.2 m of gallery per 30.4 cm^2 (fig. 3). Emerging brood adults were smaller when gallery density exceeded about 1.2 m per 30.4 cm^2. The small adult size at increased gallery densities probably is related to each larva receiving less food. Much of the food was eaten during early larval development; consequently, less food was available than was needed for the surviving larvae to reach maximum size.

The beetles from combined phloem classes 1 and 2 are smaller than those from combined phloem classes 3 and 4, even at the lowest gallery densities where little crowding would be expected. This difference suggests a qualitative difference between thin and thick phloem as food for developing larvae.

Safranyik and Jahren (1970) found beetles in lodgepole pine of small diameter are smaller than those in trees of large diameter. The smaller beetles, that are produced when most large-diameter trees with thick phloem are killed and only small trees (usually with thin phloem) remain, could be important in the dynamics of beetle populations. Small beetles from field collections have been shown to lay fewer eggs than large beetles (Amman 1972b; McGhehey 1971; Reid 1962). In addition, Cole (1973) observed that crowding during the larval stage affected the oviposition rate for beetles of similar size; adults reared from the most crowded larvae produced fewest eggs.

Small size may also affect flight capacity. Atkins (1967) found that small Douglas-fir beetles, *Dendroctonus pseudotsugae* Hopkins, contained proportionately less fat than large beetles shortly after the adult stage was reached. He found that any size beetle with low-fat content failed to fly when placed on a flight mill and, therefore, probably would have low ability to disperse in the field situation. Mountain pine beetles of small size or having low fat content could be expected to react similarly. The capacity to disperse is low when the population is low in number during early stages of stand development or after a large beetle infestation has resulted in death of most large trees. Low dispersal capacity could serve to keep the population together so that a tree could be infested and killed. However, it might be a hindrance in finding the best tree for beetle production. In addition, the possible detrimental effect of inbreeding could be expected to increase where the population remains together.

Sex ratio.--A higher proportion of females emerged from the thinnest phloem (71.9 percent) than the other phloem levels (phloem class 2 = 61.1 percent; phloem class 3 = 62.2 percent; phloem class 4 = 65.8 percent). Different proportions of females in populations emerging from trees of different sizes were noted in field populations (Cole and others, 1976); on the average, small-diameter trees (thin phloem) yielded higher proportions of females than large-diameter trees (thick phloem).

Differences in sex ratios have been attributed to crowding (Cole 1973) and to length of cold storage (Safranyik 1976; Watson 1971) in laboratory studies and to drying in field studies (Amman and Rasmussen 1974; Cole and others 1976). Differences noted in this study could not be attributed to drying because most of the material used remained moist throughout the study. Nor could the differences be entirely related to crowding because differential survival of the sexes was also apparent at low gallery densities. The data suggest that at least some of the difference is related to phloem quality, especially between phloem class 1 and the other three levels. Probably, no single factor is responsible for differential survival of the sexes, but rather any factor or combination of factors that stresses the population will result in greater survival of females than males. The greater survival of females under adverse conditions provides a larger proportion of the population to search for suitable trees to infest. The reduced survival of males may not be detrimental to the population because each surviving male can mate with several females. However, the low number of males found on some trees under attack apparently resulted in low incidence of fertilization that led to failure of attacking beetles to kill the tree and subsequent loss of brood to resinosus (Amman 1975).

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ESTIMATING FUEL WEIGHTS OF GRASSES, FORBS, AND SMALL WOODY PLANTS

James K. Brown and Michael A. Marsden[1]

ABSTRACT

Equations were developed for estimating fuel loading (g/m²) of grasses, narrow-leaved forbs, broad-leaved forbs, and small woody plants common to western Montana and north Idaho. Independent variables were plant height and percentage of ground covered. R^2 for the equations ranged from 0.30 to 0.91. The equations provide reasonable estimates for vegetation similar to that sampled in this study; however, accuracy could decrease significantly if the equations are applied to dissimilar vegetation. Differences in ocular estimates of ground cover between observers averaged 5.8 percentage points.

OXFORD: 431.2, 431.5
KEYWORDS: forest fuel, sampling methods, grass-forb biomass

Some methods for appraising potential fire behavior of fuels (Albini 1976) require :timates of loading (weight per unit area). Loadings of grass and forbs are partic- ırly important for predicting fire behavior, especially rate of spread, because these ɜls are finely divided and burn rapidly when dry. To aid in appraising fuels, a ick, easy-to-use method is needed for estimating loading. Techniques commonly used estimate loading of grass and forbs require some clipping, drying, and weighing. ɜ study reported here attempted to eliminate the need for clipping, drying, and weigh- ; by relating loading of grass and forbs to the easily obtained variables--plant ight and percentage of ground covered. The consistency of ocularly estimating ground ver was also determined.

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Previous studies gave reasonably high correlations between loading and ground cover and height; thus, we were encouraged to determine correlations for mixtures of grass and forb fuels. The simple linear correlation coefficient for the relationships between yield, and the product of ground cover and height, was 0.91 for pasture grasses (Pasto and others 1957) and annual range species (Reppert and others 1962). In both studies, correlations involving the product of ground cover and height were higher than those involving only ground cover. For several annual grasses and broad-leaved plants, Evans and Jones (1958) found simple linear correlation coefficients of 0.86 and 0.99 for the relationship between loading and the product of ground cover and height.

METHODS

FIELDWORK

Loading, height, and ground cover for mixed species of grass, forbs, and small woody plants were measured on plots 30 × 60 cm from 14 forest stands in western Montana and north Idaho. To provide a variety of understory species in the samples, stands were selected on sites that ranged from dry to moist, and in ages from newly established to mature. In each stand, 10 plots were systematically located 1 chain apart. Data were recorded for each plot unless several plots having similar species composition and ground cover had already been taken.

Each plot was categorized into grass, broad-leaved forb, narrow-leaved forb, and small woody vegetative groups (table 1). Species that dominated the ground coverage determined the vegetative groups. Species were grouped anticipating that accuracy and precision would be improved by determining weight relationships for species having similar sizes and shapes.

Plots were delineated with a 30 × 60 cm aluminum frame. The size was chosen because it was small enough to permit careful viewing for ocular estimates of ground cover and to permit clipping and weighing with reasonable effort, and it was large enough to include most plants in their entirety. At each plot, ground cover, defined as the vertical projection of plant area, was ocularly estimated to the nearest 5 percent. All grass, forb, and small woody species were included in a single estimate of ground cover for each plot. Ground cover was also determined using the line interception method (Canfield 1941). A sufficient number of line transects running lengthwise over the plots were used to estimate ground cover with a standard error within 5 percent of the mean. Height was measured to the nearest 5 cm as the distance from the forest floor to an apparent average top (plant height integrated ocularly over the plot area). All living and dead grass, forb, and small woody plant material above the forest floor within a vertical projection of the plot was clipped and ovendried at 95° C.

To determine consistency of observers in estimating ground cover, two observers independently estimated ground cover at each plot. In all, eight different observers having about one-half hour of training participated.

ANALYSIS

For each vegetative group, loading was estimated by a linear function of ground cover and height. Groups were tested to see if some of them could be combined without significant loss of ability to predict. Using linear regression analysis, log transformations were evaluated for both the dependent variable (loading) and several expressions of the independent variables (ground cover and height). The log transformations were discarded in favor of using loading in its original units as the dependent variable. Loading was then regressed on logical sets (models) of the following independent variables: ground cover, height, height squared, and the interactions of ground cover with height and height squared.

Table 1.--*Species groups and species dominating ground cover*[1]

Species group		Dominant species	
Grass	1.	Pinegrass	*Calamagrostis rubescens*
	2.	Elk sedge	*Carex geyeri*
	3.	Beargrass	*Xerophyllum tenax*
	4.	Pinegrass or elk sedge	
Broad-leaved forb	5.	Arnica	*Arnica* spp.
	6.	Bedstraw	*Galium* spp.
	7.	Pussytoes	*Antennaria* spp.
	8.	Strawberry	*Fragaria* spp.
	9.	Twisted stalk	*Streptopus amplexifolius*
	10.	Meadow rue	*Thalictrum* spp.
	11.	Western gold thread	*Coptis occidentalis*
	12.	Wintergreen	*Pyrola* spp.
	13.	Anemone	*Anemone* spp.
	14.	Queencup beadlily	*Clintonia uniflora*
	15.	Lady fern	*Athyrium distentifolium*
	16.	Violet	*Viola* spp.
Narrow-leaved forb	17.	Fireweed	*Epilobium angustifolium*
	18.	Goldenrod	*Solidago* spp.
	19.	Canada thistle	*Cirsium arvense*
	20.	Yarrow	*Achillea millefolium*
	21.	Flannel mullein	*Verbascum thapsus*
	22.	Fairy bell	*Disporum hookeri*
	23.	Bracken fern	*Pteridium aquilinum*
Small woody plants	24.	Kinnikinnick	*Arctostaphylos uva-ursi*
	25.	Twinflower	*Linnaea borealis*

[1] Species of minor occurrence are omitted from the listing.

RESULTS AND DISCUSSION

The prediction equations in table 2, and figures 1 and 2, all exhibited F ratios significant at the 99 percent level. For the range of data on which the equations are based, the predictions are reasonable. However, our data suggest that incorporating several species, even though of similar growth form, into a single prediction equation results in less accuracy than equations developed for single species. The equation for small woody plants had the best accuracy, probably because it was developed almost entirely from one species--kinnikinnick. This equation should be suitable for estimating loading of kinnikinnick for many purposes.

The equation for grass had the poorest accuracy, perhaps partly because ground cover is difficult to ocularly estimate. Narrow-leaved blades and stalks oriented primarily in an upright position create a fuzzy impression of how much ground surface is covered by a vertical projection of plant area.

Table 2.--*Equations for estimating loading (Y), g/m², from ground cover (X_1), and height (X_2), cm*

Species group	Equations	R^2	CV[1]
			Percent
Grass	$Y = 6.102 + 2.83\ (X_1) + 2.432\ (X_2)$	0.30	67
Narrow-leaved forbs	$Y = 192.4 + 0.05680\ (X_2X_1) + 0.000914\ (X_2^2X_1) - 0.05242\ (X_2^2)$	.77	55
Broad-leaved forbs	$Y = -13.80 + 1.388\ (X_1) - 0.03040\ (X_1X_2) + 1.156\ (X_2)$	.68	41
All forbs combined	$Y = -28.14 + 0.001535\ (X_2^2X_1) + 8.926\ (X_2) - 0.1256\ (X_2^2)$	.80	67
Small woody	$Y = 109.0 - 2.161\ (X_1) + 0.1078\ (X_1^2)$	.91	23

[1] The coefficient of variation of the average predicted values, $\hat{Y}$'s, is estimated by SE $(\hat{Y})/\bar{Y}$.

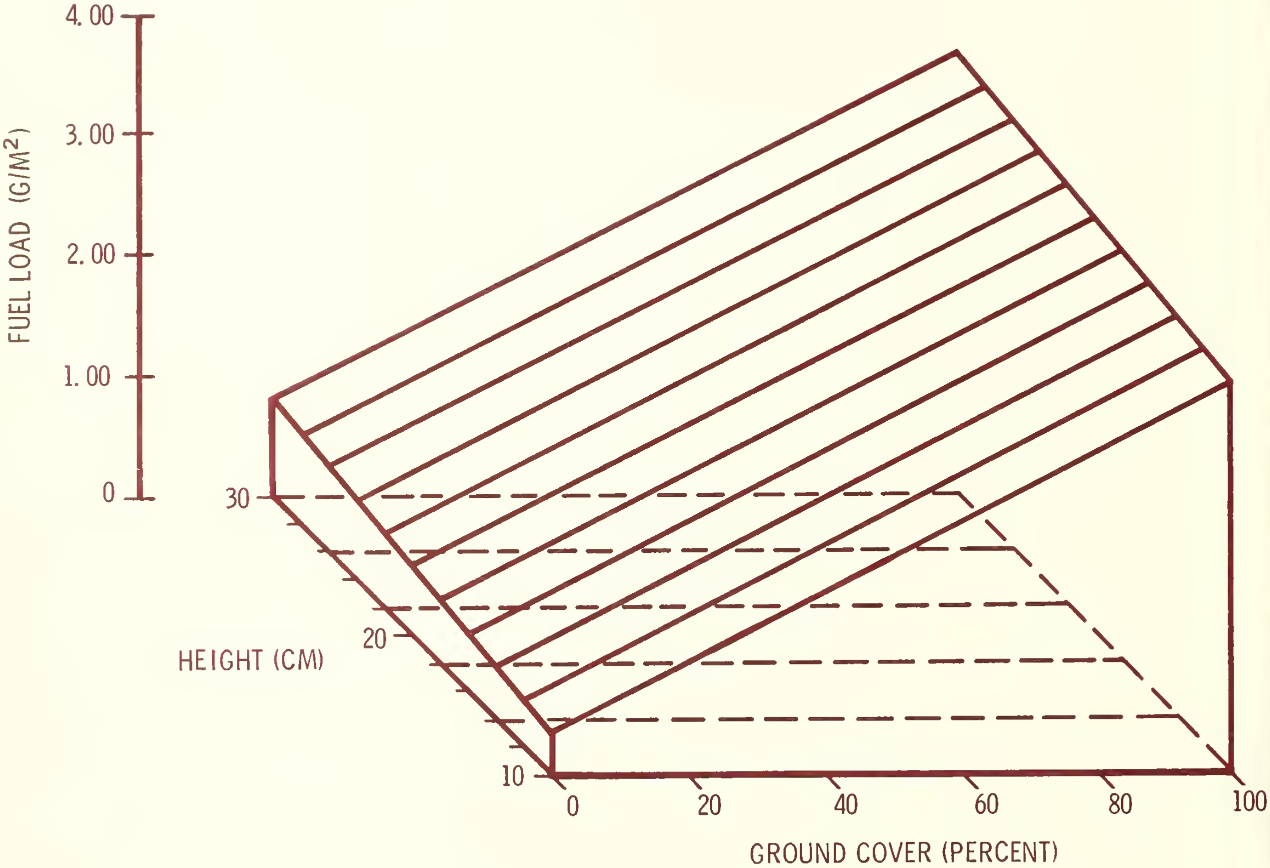

Figure 1.--Loading of grass as a function of coverage and height.

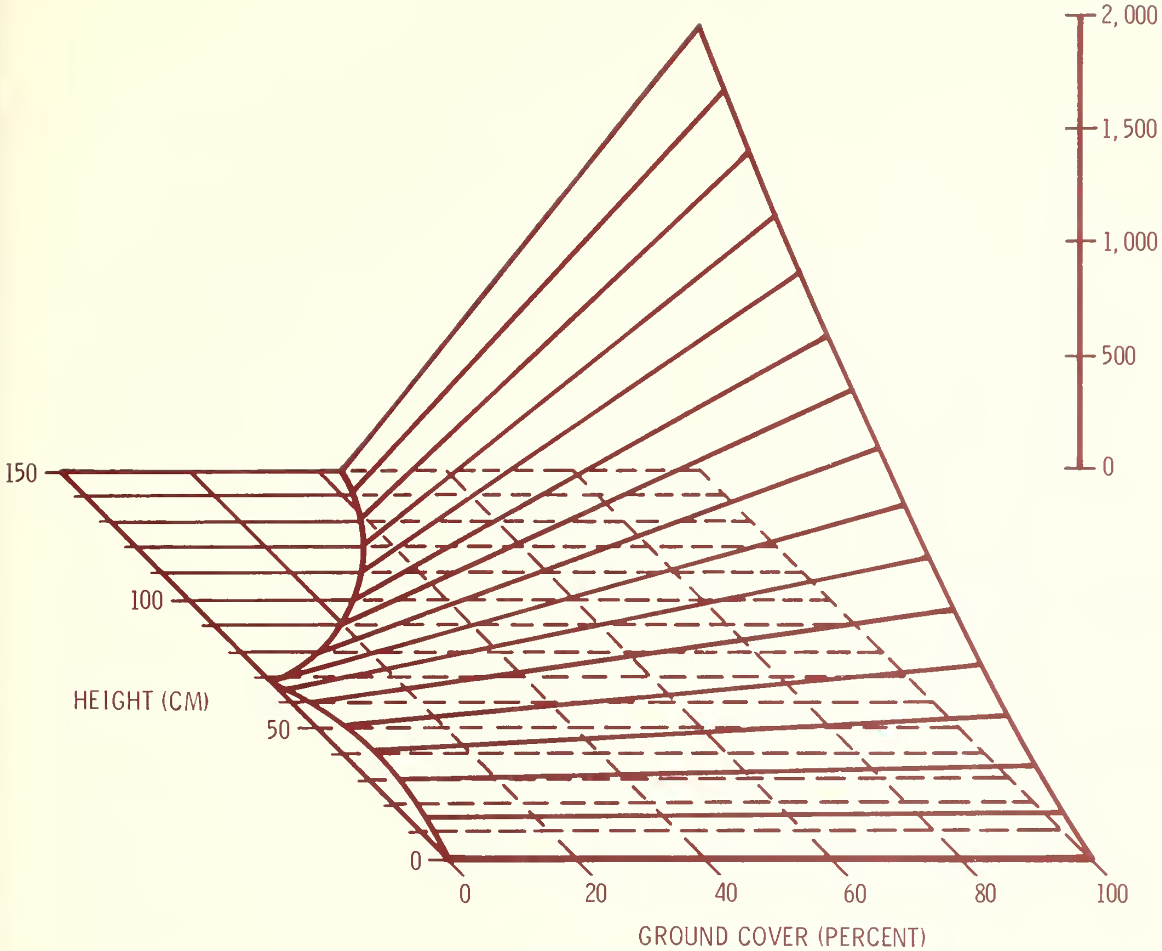

Figure 2.--Loading of broad- and narrow-leaved forbs combined as a function of coverage and height.

The use of separate equations for broad-leaved and narrow-leaved forbs did not produce significantly different predictions. This indicates that a combined forb equation could be used for estimating loading of all forbs. Our combined forb equation had a higher coefficient of variation than equations for either of the forb groups alone, which one might expect from combining data. This equation yields negative values for some combinations of ground cover (below 40 percent) and heights greater than 50 cm (fig. 2). More study is needed to determine whether a combined forb model can be developed that is adequately accurate for prediction over a range of ground covers and heights that might be encountered in the field. Our data are listed in the appendix in the event others wish to expand this study.

To help evaluate accuracy, measured loadings from another study[2] were compared with predicted loadings using some of the equations in table 2. Because the forbs were dominantly broadleaf type, predictions were made using the broadleaf as well as combined forb equations (table 3). In most cases, the broadleaf equation yielded smaller deviations than the combined forb equation. Average deviations expressed as the difference between predicted values and observed values divided by observed values ranged from a

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[2]Aldrich, David F. and Robert W. Mutch. 1972. Ecological interpretations of the White Cap Drainage: a basis for wilderness fire management, 109 p. USDA For. Serv., Intermt. For. and Range Exp. Stn. Prog. Rep. (Rev. Draft), North. For. Fire Lab., Missoula, Mont.

Table 3.--*Average deviations for loadings of grass and forbs from several habitat types in the Selway-Bitterroot Wilderness, expressed as predicted minus observed values divided by observed values*

Habitat type	Species group	No. of plots	Average deviations Actual	Average deviations Absolute
Abies lasiocarpa/Menziesia ferruginea	Broad-leaved forb	25	-0.81	0.83
	Combined forb	25	-.19	.53
Abies lasiocarpa/Clintonia uniflora	Broad-leaved forb		-.43	.56
	Combined forb	19	1.06	1.47
Abies grandis/Clintonia uniflora	Broad-leaved forb		-.22	.93
	Combined forb	91	1.11	1.50
Pseudotsuga menziesii/Xerophyllum tenax	Grass	13	2.28	2.35
Abies lasiocarpa/Xerophyllum tenax	Grass	116	-.15	.91

-0.15 to 2.28. In part, the large deviations were probably due to using the wrong equation for prediction. We were unsure of the species actually present because a list of species sampled was unavailable.

In developing equations that use ocular estimates of ground cover as an independent variable, the consistency of different observers comes into question. We found that consistency of different observers estimating ground cover on the same plots was rather good. In the test of consistency, ground cover ranged from 12 to 32 percent and averaged 22 percent. For the four pairs of observers, differences in ground cover estimates between observers ranged from 1.5 to 8.7 percent and averaged 5.8 percent.

This study shows that as different plant sizes and shapes are added to the data base for developing predictive equations, poorer accuracy can be expected. For appraising grass and forb fuels on specific sites, the mixed species equation from this study would provide questionable accuracy. To obtain adequate site-specific information, a technique involving some clipping and weighing seems necessary. However, for appraising fuels in broad vegetative groups, relationships between loading and ground cover and height can provide reasonable estimates.

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APPENDIX

Table 4.--*Raw data from plots of 1,800* cm^2 *and predicted (P) minus observed (0) values expressed as a fraction of predicted values*

Stand ID	Dominant species[1]	Height	Cover	Observed loading	$\frac{P - 0}{P}$
		SMALL WOODY PLANTS			
		Cm	*Percent*	*G/plot*	
1	24,1	10	30	32.6	- 0.28
1	24	10	10	12.1	.32
1	24,1	10	88	101.6	.25
1	24,1	10	53	48.0	.10
1	24,1	15	12	16.3	.08
1	24	10	95	191.6	- .21
1	24,1	10	55	65.1	- .14
1	24,3	10	17	16.5	.11
3	24,1,5	10	65	83.7	- .10
3	24,1	10	15	8.7	.52
3	24,1	10	65	75.4	.01
3	24,1	10	15	24.1	- .33
3	24,1,7	10	50	46.9	.04
3	24,1	10	55	52.4	.08
3	24	10	38	55.8	- .70
3	24,1	10	53	62.2	- .16
3	24,3	10	17	17.4	.07
3	24,3	10	65	69.9	.08
3	24,3	10	38	44.0	- .34
3	24,3	10	18	14.4	.24
3	24,1	10	50	49.8	- .02
3	24,1	10	70	85.4	.02
3	24,3	10	62	65.7	.06
3	24	10	38	40.6	- .24
3	24,1	10	11	9.5	.46
3	24,1,20	10	53	48.7	.09
3	24,1	10	63	45.0	.38
3	24,3	10	22	22.5	- .10
3	24,1,7	10	83	112.8	.07
3	24,1	10	22	27.6	- .35
3	24,1	10	32	26.3	.03
3	24	10	90	151.7	- .07

[1]See table 1 for numbered listing of species.

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	$\frac{P - 0}{P}$
		BROAD-LEAVED FORBS			
		Cm	*Percent*	*G/plot*	
1	5	15	90	15.1	0.23
1	5	10	35	4.9	.50
1	5	10	10	1.6	.82
1	5	10	15	3.1	.66
1	5,1	10	30	5.4	.44
1	5,1	10	85	11.8	- .06
1	5,1	10	10	3.6	.60
1	5	20	35	3.9	.82
1	5	20	60	6.0	.76
3	5,1,10	10	85	19.8	- .79
3	5,10,25	10	70	17.0	- .59
3	5,1,25	10	95	19.0	- .67
11	5	5	10	1.5	.39
11	5	10	10	1.9	.79
13	5,1,8,24	14	52	15.6	.01
13	9,1,24	22	17	6.0	.72
13	7,1,8,25	9	61	15.0	- .68
22	5,6,9,25	15	58	11.4	.35
22	5,9	15	51	3.5	.80
22	5,9,11	15	60	5.7	.68
22	5	35	63	8.4	.81
31	5,12,11	20	68	7.1	.72
31	5,3	20	72	20.2	.22
32	14,11,25	13	23	2.8	.79
32	5,9,11,25	45	78	9.2	.86
32	11,9,25	12	28	4.2	.65
32	11,9,25	20	43	5.7	.75
32	5,9,22,11	25	81	8.7	.75
33	5,8	45	26	8.2	.77

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	$\frac{P-O}{P}$
		GRASSES			
		Cm	*Percent*	*G/plot*	
1	3	20	27	35.6	- 0.51
1	3	20	56	81.2	- 1.12
1	3	20	55	53.8	- .42
1	3	20	13	7.8	.53
1	3	20	9	7.6	.47
1	3	20	14	10.8	.36
1	3	20	51	85.2	- 1.38
1	3	30	60	93.1	- 1.08
3	1,2	10	90	71.2	- .39
3	1,2	10	95	68.7	- .28
3	1,2,5,7	10	80	49.7	- .07
3	4,5,8,10	10	95	44.8	.17
3	1,5	10	85	30.3	.38
11	1,5,6,25	12	18	2.6	.83
11	1	10	10	1.3	.88
11	1,5,7	10	45	7.9	.72
11	1,5	15	35	9.6	.62
11	1,5	10	17	5.0	.65
11	1,5,6,8	22	38	6.9	.77
11	1,5,8,25	21	58	17.9	.55
12	3	7	14	8.3	.27
12	3	17	49	33.5	.00
12	3,22	9	38	12.5	.49
13	1,5,8	27	39	13.9	.58
13	1,5,6	12	42	18.6	.33
13	3,22	20	46	38.2	- .15
13	1,5,6	17	29	4.3	.82
13	1,5,6,7	22	40	9.9	.68
21	3,9,25	35	58	52.5	- .14
21	3,12	7	12	40.7	- 2.96
21	3,11	20	41	48.8	- .59
21	3,11,12	25	88	13.3	.77
22	3	13	68	60.4	- .46
23	1,9,22	50	85	48.9	.26
23	4,11	10	75	23.6	.46
23	4,10,6,9	10	30	20.4	.02
32	3	10	75	75.6	- .73
32	3	20	23	58.8	- 1.73
34	4,9	10	70	17.2	.58
34	4,5,10	10	70	46.0	- .12
35	1,5,10	10	85	40.0	.18

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	$\frac{P - 0}{P}$
		NARROW-LEAVED FORBS			
		Cm	*Percent*	*G/plot*	
1	19	75	90	150.7	- 0.18
1	18,19	50	32	39.8	.03
1	18,19	60	82	96.9	- .06
1	18,19	45	50	75.5	- .53
1	18	40	9	13.1	.51
1	18	30	30	26.1	.14
1	18,19	55	55	131.1	- 1.15
1	18,20	65	29	65.1	- .73
1	19	50	52	58.2	- .06
1	18	60	48	99.3	- .72
1	18	40	16	13.0	.57
1	18,7	30	7	7.5	.69
1	18,19	35	52	53.6	- .31
1	18	20	30	17.1	.20
1	18	30	48	30.5	.12
1	18	65	11	29.1	- .75
1	17,7	73	75	88.2	.14
1	17,5	55	83	89.1	- .06
1	17,7	73	18	31.3	- .72
1	17	45	62	65.8	- .17
1	17,5,10	41	82	111.8	- .84
1	17	60	18	11.7	.58
1	19,17,21	71	80	84.8	.20
1	17,5	55	94	129.0	- .38
1	17	100	62	14.7	.85
1	17	45	27	21.7	.41
1	17	100	34	49.0	- 1.09
1	20,8	10	25	25.6	- 1.71
1	17,21	27	65	150.6	- 3.31
1	21	45	37	41.2	.02
1	17,5	77	25	30.7	- .20
1	17	100	45	102.8	- .91
1	17	55	15	14.0	.49
1	17,1	72	30	41.9	- .15
1	17,1	55	49	50.8	.09
1	17,5,8	15	95	96.6	- 3.87
20	23	125	99	221.5	.18
20	23	115	99	274.4	- .13
20	23	100	99	195.4	.04
20	23	150	99	387.7	- .13
20	23,9	135	99	495.1	- .66
20	23	150	99	416.3	- .22

Table 4.--(con.)

Stand ID	Dominant species	Height	Cover	Observed loading	(P - O)/P
		NARROW-LEAVED FORBS (con.)			
		Cm	*Percent*	*G/plot*	
20	23	150	99	205.2	.40
20	23	135	99	306.0	- .03
20	23	110	99	90.4	.61
20	23	105	99	254.6	- .18
23	22	75	45	35.2	.39
23	22	10	70	20.9	- .96
23	19,8,25	14	38	21.8	- .45
23	23	25	41	19.4	.31
23	22,6	35	68	31.9	.31
23	22,6,11	21	17	5.4	.74
23	17,1	130	88	118.6	.49

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Research Note INT-211

October 1976

HERBICIDES USED FOR CONTROL OF LESSER VEGETATION DAMAGE YOUNG LODGEPOLE PINE

Dennis M. Cole[1]

ABSTRACT

Herbicides used to kill understory vegetation caused mortality and reduced height growth of young leave-trees in a lodgepole pine spacing study designed to test the effect of removing competing vegetation. Both mortality and height growth reduction occurred during the first 2 years following herbicide treatment, apparently the result of too much herbicide being applied too early in the growing season. Growth processes did not appear to be permanently affected.

OXFORD: 416.1, 414.13

KEYWORDS: herbicide effects, tree damage, lodgepole pine (*Pinus contorta* Dougl.), vegetation control

In 1965-1966, a study was installed on the Lewis and Clark National Forest in central Montana to provide information on lodgepole pine tree growth and stand development under different initial spacings. Another objective of the study was to determine the effect of the presence and absence of understory vegetation on the growth and development of the young trees at the various spacings.

Two replications of five square spacings--6, 9, 12, 15, and 18 feet--were installed in a random block design. To test the influence of competing vegetation, one-half of each spacing plot was sprayed with herbicides to kill the understory species, and the other half left unsprayed. The herbicides, intended to kill only the understory vegetation, caused unexpected tree mortality and reduced height increment of trees on the sprayed areas. This Note describes the study, herbicide application, the extent of damage, and suggests methods for minimizing herbicide damage in similar situations.

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[1]Research forester stationed in Bozeman, Montana, at the Intermountain Station's Forestry Sciences Laboratory.

BACKGROUND

Plots were established in an 8- to 10-year-old natural stand growing in an 18-acre clearcut. Lodgepole pine site index (at 100 years) was estimated at 55 feet, from measurements taken in the surrounding mature stand. The soils (described by Herbert Holdorf, USDA Forest Service, Soils Scientist, Lewis and Clark National Forest) are deep, light colored, formed in stony loam or heavy sandy loam material weathered from the underlying granitic bedrock, medium acid in reaction, take in water readily, are well drained, and contain no restrictions to root development. The forest vegetation is classified as an *Abies lasiocarpa/Vaccinium scoparium* habitat type.[2] Species in the understory were grouse whortleberry (*Vaccinium scoparium*), lupine (*Lupinus* spp.), and elk sedge (*Carex geyeri*). The area is essentially flat and located at 6,400 feet elevation.

Thinning was done in August 1965; slash was allowed to cure and compact until the following August, when the herbicides were applied during the period August 9-12. No rainfall was recorded in the few days before, during, and after the herbicide application.

The spray mixture contained 5 pounds active ingredient (ai) sodium salt of dalapon (2,2-dichloropropionic acid), 4.5 pounds acid equivalent (ae) low volatile propylene glycol butyl ether (PGBE) esters of 2,4-D (2,4-dichlorophenoxyacetic acid), and 4.5 pounds ae low volatile PGBE esters of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) per 100 gallons. The chemicals were mixed in water.

Herbicides were applied with a 3-foot-wide, hand-held spray boom and a portable power sprayer having output capacity of 3 gallons per minute at 60 lb. pressure per square inch. Spray was applied to the understory vegetation until it dripped. The spray was carefully directed downward and away from the foliage of leave-trees. Despite this precaution, evidence of damage to leave-trees developed within a few weeks after spraying and became more pronounced throughout the fall of 1966, resulting in death of some trees (no damage was noted in unsprayed subplots). To assess the effects damage surveys were made in August 1967 and September 1968. All trees on the sprayed subplots were examined and rated for herbicide effect by the following code:

0 = unaffected
1 = slightly affected
2 = serious foliage reduction and/or leader loss
3 = dead.

Heights of trees tagged and measured for the spacing study were remeasured in September 1970, four growing seasons following herbicide treatment.

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[2]Pfister, Robert D. and others. 1974. Forest habitat types of Montana. USDA For. Serv., Intermt. For. and Range Exp. Stn. and North. Reg., Missoula, Mont. Review draft, 213 p.

HERBICIDE EFFECTS

Tree Damage and Mortality

The herbicides damaged and killed trees on all sprayed subplots; however, no differences in the pattern of damage due to spacing and block effects were noted. The condition of lodgepole pine trees damaged by herbicides, 1 year and 2 years after spraying was as follows:

Damage Code - Description	*After 1 Year* (*Percent*)	*After 2 Years* (*Percent*)
0 - unaffected	41	45
1 - slightly affected	31	17
2 - seriously affected	21	22
3 - dead	7	16

One year after spraying, mortality averaged 7 percent on the sprayed subplots; and 52 percent were damaged by the herbicides. Nearly half of the damaged trees were seriously affected. Damage after 2 years showed a similar pattern--the most notable difference being an increase in mortality to double that of a year earlier. The increased mortality was due to death of trees that had been seriously affected the previous year. About 75 percent of the trees that had been only slightly affected in the first survey were seriously affected the following year, while the other 25 percent recovered. Examination of the study 3 years after herbicide treatment revealed no further mortality and no further deterioration in tree condition; therefore, damage was no longer recorded.

Four growing seasons after herbicide treatment, average 6-year height increment (adjusted for heights before treatment) was significantly less (0.01 level) on sprayed subplots than on unsprayed subplots. In fact, herbicide treatment was the only statistically significant source of variation in height growth at the time of remeasurement. The 6-year height increment (in 1970) was as follows:

Spacing (*Feet*)	*Sprayed* (*Feet*)	*Unsprayed* (*Feet*)
6 by 6	2.6	4.4
9 by 9	3.6	4.5
12 by 12	3.3	4.4
15 by 15	3.6	4.4
18 by 18	3.0	3.5

Effect on Understory Vegetation

All understory vegetation appeared to be killed by the herbicides, when examinations were made the summer following spraying. By the second year after spraying, however, the sprayed areas were rather uniformly occupied by cheatgrass (*Bromus tectorum* L.), an aggressive invader. Four years after spraying, lupine was becoming reestablished on the sprayed areas.

DISCUSSION AND CONCLUSIONS

The combination and amounts of herbicides used in this study (dalapon, 5 lbs ai; 2,4-D, 4.5 lb ae; and 2,4,5-T, 4.5 lb ae; per 100 gallons of water) seriously reduced the growth and survival of young lodgepole pines. Although all of the herbicides are considered selective in that they have demonstrated greater toxicity to grasses (dalapon) and broad-leaved species (2,4-D and 2,4,5-T) than to conifers, the effect of the particular combination used was not well understood--at least for lodgepole pine.

Greater susceptibility to 2,4-D than 2,4,5-T has been shown for ponderosa pine and sugar pine (Gratkowski 1961; Schubert 1962). Earlier, in an attempt to kill excess trees, young lodgepole pines in Alberta were killed by 2,4-D in diesel oil (Crossley 1950); in this case, the diesel oil probably increased the effect of the herbicide by acting as a cuticular solvent (Gratkowski, H., personal communication). Because the chemicals were combined in this study, it can only be speculated as to whether the trees were affected more by one herbicide than the other, or whether a synergistic effect was created by combining herbicides.

The season of application is important in silvicultural use of phenoxy herbicides, such as 2,4-D and 2,4,5-T; generally the pines are more sensitive to these herbicides than are Douglas-fir and the spruces (Arend 1955; Walker 1967; Gratkowski 1975). Among the pines, differences in seasonal susceptibility to phenoxy herbicide have been found for ponderosa pine and sugar pine (Gratkowski 1970); jack pine and red pine (Walker 1967); and jack pine versus red pine, eastern white pine, and Scotch pine (Arend 1955). In the latter two cases, jack pine (an interbreeding species with lodgepole pine) exhibited susceptibility to 2,4-D and 2,4,5-T in Michigan and Manitoba when sprayed after August 1, while the other pines were relatively unaffected.

Although the amount of 2,4-D and 2,4,5-T applied per acre in this study seems about twice the rate observed elsewhere, the amount the trees actually received is not known. Also, the possibility that this combination of herbicides at the rates applied can express its effect through the soil cannot be discounted. Whatever the reason for damage, it is clear that the amounts of herbicides used were excessive for young lodgepole pines.

The apparent effects of the herbicides on the trees lasted about 2 to 3 years. Mortality essentially ceased beyond this period, and a recovery of affected trees was noted in the third year following herbicide treatment. The herbicide effect on height growth appears to be temporary; the apical meristems and terminal leaders are affected for a year or two, causing loss of leaders and disruption of normal meristem development in the upper whorl. Nonetheless, these effects should not be casually dismissed. Growth research on many species has affirmed the fact that height growth reduction or loss, whatever the cause, cannot be recovered.

Factors requiring careful consideration in using herbicides in silviculture include: (1) insuring that herbicides are registered for use by the Environmental Protection Agency and approved for use on forest lands in the respective state; (2) selecting the silviculturally proper herbicide(s) and correct season(s) for application; (3) determining the minimum number of appropriate herbicides that will accomplish objectives, thus minimizing possible synergistic effects on trees; and (4) use of minimum amounts of herbicide to achieve the degree of control needed.

For this study, it is concluded that (1) combined amounts of phenoxy herbicides (2,4-D and 2,4,5-T) were excessive, not only for the health of the trees, but also for the vegetation control desired; and (2) the phenoxy herbicides were applied before summer growth had ceased. To be on the safe side, phenoxy herbicides for understory vegetation control in young lodgepole pine stands should not be applied until at least the first week in September or until all summer growth has definitely ceased (Gratkowski 1975).

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RELATIONSHIP OF STUMP DIAMETER TO DIAMETER AT BREAST HEIGHT FOR SEVEN TREE SPECIES IN ARIZONA AND NEW MEXICO

David W. Hann, Research Forester

ABSTRACT

Presents equations and tables for estimating diameter at breast height from stump diameter for ponderosa pine ("yellow" and "blackjack" pine separately), Douglas-fir, aspen, white fir, southwestern white pine, and from combined data for Engelmann spruce and corkbark fir. The basic data came from five National Forests in Arizona and New Mexico, and were analyzed using weighted least squares regression techniques.

KEYWORDS: diameter measurements (stem), stump-d.b.h., conversion tables

When reconstructing temporary growth plots, or when conducting a forest inventory r a timber trespass appraisal, it is often necessary to estimate a cut tree's volume y estimating its diameter at breast height (d.b.h.) from the diameter of the remaining tump and an estimate of the height of the removed tree. An estimate of tree height an be obtained by the d.b.h.-tree height relationship of other trees in the area or by easuring the distance from the stump to the top remnants, if they exist. This paper resents estimated d.b.h. values for given stump diameters for seven tree species in rizona and New Mexico.

DATA SOURCES AND METHODS

The data used in this study were collected from five National Forests by field rews from the Division of Timber Management, Southwestern Region, Forest Service, buquerque, New Mexico (table 1).

In the study area, "Blackjack" and "yellow" pines are distinguished on the basis f bark color that is related to their age, growth, and vigor rather than botanically; blackjack" pines have very dark bark and "yellow" pines heavily plated, orange bark. oresters in the Southwest find this distinction useful in forest management planning.

Table 1.--*Data sources.*

SPECIES	NATIONAL FOREST				
	Coconino	Tonto	Lincoln	Santa Fe	Carson
"Blackjack pine" (*Pinus ponderosa* Laws.)	X	X	X	X	X
"Yellow pine" (*Pinus ponderosa* Laws.)	X	X	X	X	X
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco)		X	X	X	X
White fir (*Abies concolor* [Gord. and Glend.] Lindl.)			X	X	X
Southwestern white pine (*Pinus flexilis* var. *reflexa* Engelm.)			X	X	X
Aspen (*Populus tremuloides* Michx.)				X	X
Engelmann spruce (*Picea engelmannii* Parry)				X	X
Corkbark fir *Abies lasiocarpa* var. *arizonica* [Merriam] Lemm.)				X	X

Stump diameter, inside bark, was determined by averaging the measurements of the long and short axes of the stump's cross section. Stump height, measured on the uphill side, was 1.0 foot on all National Forests except the Lincoln. On the Lincoln, stump height was 1.2 feet. Each tree's d.b.h., outside bark, was measured with a diameter tape before the tree was felled.

It was hypothesized that d.b.h. is linearly related to stump diameter. Therefore, the following model was fitted to the data using least squares regression:

$$D = b_0 + b_1(D_s)$$

where D = diameter at breast height, outside bark, in inches

D_s = stump diameter, inside bark, in inches

An examination of residuals indicated that this model was appropriate, but it also revealed that the squared residuals increased as a linear function of stump diameter. Because of this, the reciprocal of stump diameter was taken as the weight in the weighted least squares regression program used for the rest of the study.

Analyses of covariance determined that data sets could be combined across National Forests for each species and that the data set for corkbark fir could be combined with that for Engelmann spruce. As a result, the data for all forests, except the Lincoln (because of the different stump height), were combined.

The range in stump diameters for each data set, final weighted least squares regression coefficients, the number of trees used in their development, and the resulting coefficients of determination are presented in table 2. Two of the data sets, "yellow" pine on the Lincoln and white pine on the Santa Fe and Carson National Forests, were weak in terms of number of trees, but the resulting equations seemed reasonable and so are included. Tabular values of these equations are given in appendix tables 3 through 14.

When these results are used, it is strongly recommended that stump diameter be computed as the average of the long and short axes. The use of a diameter tape on out-of-round stems can produce results that differ considerably from the recommended method.

Table 2.--*Data base and regression results*

Species	National Forest	Number of trees	Range in stump diameters, inside bark	Regression coefficients		R^2 Coefficient of determination
				b_0	b_1	
			Inches			
outhwestern white pine	Santa Fe, Carson	18	5.3 - 21.8	0.6805	0.9154	0.9560
outhwestern white pine	Lincoln	42	5.0 - 41.6	.3744	.9526	.9905
ngelmann spruce and corkbark fir	Santa Fe, Carson	161	4.7 - 24.1	.5489	.8779	.9591
Yellow" pine	Santa Fe, Carson, Coconino, Tonto	220	7.0 - 33.0	1.8887	.9528	.9503
Yellow" pine	Lincoln	11	11.4 - 30.7	1.0068	.9967	.9569
Blackjack" pine	Santa Fe, Carson, Coconino, Tonto	963	4.3 - 29.2	.5520	1.0156	.9699
Blackjack" pine	Lincoln	57	4.4 - 19.7	.6582	1.0060	.9828
ouglas-fir	Santa Fe, Carson, Tonto	115	4.7 - 25.1	.2223	1.0002	.9694
ouglas-fir	Lincoln	93	5.1 - 35.4	.6464	1.0056	.9803
spen	Santa Fe, Carson	145	4.6 - 21.3	.3280	.9691	.9615
hite fir	Santa Fe, Carson	66	4.4 - 29.0	.4499	.9636	.9814
hite fir	Lincoln	48	4.3 - 49.0	.6265	.9800	.9909

APPENDIX

TABLE 3. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
SOUTHWESTERN WHITE PINE
SANTA FE, CARSON N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - - -	- - - - -	- - - - -	D.B.H.	IN INCHES	- - - - -	- - - - -	- - - - -		
5	5.3	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.4	6.5	6.6	6.7	6.8	6.9	7.0
7	7.1	7.2	7.3	7.4	7.5	7.5	7.6	7.7	7.8	7.9
8	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.6	8.7	8.8
9	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.7
10	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7
11	10.8	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
12	11.7	11.8	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5
13	12.6	12.7	12.8	12.9	12.9	13.0	13.1	13.2	13.3	13.4
14	13.5	13.6	13.7	13.8	13.9	14.0	14.0	14.1	14.2	14.3
15	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.1	15.2
16	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2
17	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1
18	17.2	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0
19	18.1	18.2	18.3	18.3	18.4	18.5	18.6	18.7	18.8	18.9
20	19.0	19.1	19.2	19.3	19.4	19.4	19.5	19.6	19.7	19.8
21	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.5	20.6	20.7
22	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.6
23	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6
24	22.7	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5
25	23.6	23.7	23.7	23.8	23.9	24.0	24.1	24.2	24.3	24.4
26	24.5	24.6	24.7	24.8	24.8	24.9	25.0	25.1	25.2	25.3
27	25.4	25.5	25.6	25.7	25.8	25.9	25.9	26.0	26.1	26.2
28	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0	27.0	27.1
29	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1
30	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0
31	29.1	29.2	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9
32	30.0	30.1	30.2	30.2	30.3	30.4	30.5	30.6	30.7	30.8
33	30.9	31.0	31.1	31.2	31.3	31.3	31.4	31.5	31.6	31.7
34	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.4	32.5	32.6
35	32.7	32.8	32.9	33.0	33.1	33.2	33.3	33.4	33.5	33.5

TABLE 4. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.2-FOOT-HIGH STUMP
SOUTHWESTERN WHITE PINE
LINCOLN N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	D.B.H. IN INCHES									
5	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
6	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	6.9
7	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9
8	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
9	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8
10	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8
11	10.9	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7
12	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7
13	12.8	12.9	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6
14	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6
15	14.7	14.8	14.9	14.9	15.0	15.1	15.2	15.3	15.4	15.5
16	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5
17	16.6	16.7	16.8	16.9	16.9	17.0	17.1	17.2	17.3	17.4
18	17.5	17.6	17.7	17.8	17.9	18.0	18.1	18.2	18.3	18.4
19	18.5	18.6	18.7	18.8	18.9	18.9	19.0	19.1	19.2	19.3
20	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1	20.2	20.3
21	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.0	21.1	21.2
22	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1	22.2
23	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23.0	23.0	23.1
24	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0	24.1
25	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.0
26	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0
27	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0
28	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9
29	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9
30	29.0	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8
31	29.9	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8
32	30.9	31.0	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7
33	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7
34	32.8	32.9	33.0	33.0	33.1	33.2	33.3	33.4	33.5	33.6
35	33.7	33.8	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6

TABLE 5. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
ENGELMANN SPRUCE-CORKBARK FIR
SANTA FE, CARSON N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - - - -	-	-	-	D.B.H.	IN INCHES	-	-	-	- - - - - -
5	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.6	5.7
6	5.8	5.9	6.0	6.1	6.2	6.3	6.3	6.4	6.5	6.6
7	6.7	6.8	6.9	7.0	7.0	7.1	7.2	7.3	7.4	7.5
8	7.6	7.7	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4
9	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.2
10	9.3	9.4	9.5	9.6	9.7	9.8	9.9	9.9	10.0	10.1
11	10.2	10.3	10.4	10.5	10.6	10.6	10.7	10.8	10.9	11.0
12	11.1	11.2	11.3	11.3	11.4	11.5	11.6	11.7	11.8	11.9
13	12.0	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8
14	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.5	13.6
15	13.7	13.8	13.9	14.0	14.1	14.2	14.2	14.3	14.4	14.5
16	14.6	14.7	14.8	14.9	14.9	15.0	15.1	15.2	15.3	15.4
17	15.5	15.6	15.6	15.7	15.8	15.9	16.0	16.1	16.2	16.3
18	16.4	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1	17.1
19	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.8	17.9	18.0
20	18.1	18.2	18.3	18.4	18.5	18.5	18.6	18.7	18.8	18.9
21	19.0	19.1	19.2	19.2	19.3	19.4	19.5	19.6	19.7	19.8
22	19.9	20.0	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7
23	20.7	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.4	21.5
24	21.6	21.7	21.8	21.9	22.0	22.1	22.1	22.2	22.3	22.4
25	22.5	22.6	22.7	22.8	22.8	22.9	23.0	23.1	23.2	23.3
26	23.4	23.5	23.5	23.6	23.7	23.8	23.9	24.0	24.1	24.2
27	24.3	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.0
28	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.7	25.9	25.9
29	26.0	26.1	26.2	26.3	26.4	26.4	26.5	26.6	26.7	26.8
30	26.9	27.0	27.1	27.1	27.2	27.3	27.4	27.5	27.6	27.7
31	27.8	27.9	27.9	28.0	28.1	28.2	28.3	28.4	28.5	28.6
32	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.3	29.4
33	29.5	29.6	29.7	29.8	29.9	30.0	30.0	30.1	30.2	30.3
34	30.4	30.5	30.6	30.7	30.7	30.8	30.9	31.0	31.1	31.2
35	31.3	31.4	31.5	31.5	31.6	31.7	31.8	31.9	32.0	32.1

TABLE 6. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
"YELLOW" PINE
SANTA FE, CARSON, COCONINO, TONTO N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
					D.B.H. IN INCHES					
5	6.7	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5
6	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
7	8.6	8.7	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4
8	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4
9	10.5	10.6	10.7	10.7	10.8	10.9	11.0	11.1	11.2	11.3
10	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2	12.3
11	12.4	12.5	12.6	12.7	12.8	12.8	12.9	13.0	13.1	13.2
12	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2
13	14.3	14.4	14.5	14.6	14.7	14.8	14.8	14.9	15.0	15.1
14	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1
15	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.8	16.9	17.0
16	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0
17	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.8	18.9
18	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9
19	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.8
20	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8
21	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8
22	22.9	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7
23	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7
24	24.8	24.9	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6
25	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6
26	26.7	26.8	26.9	26.9	27.0	27.1	27.2	27.3	27.4	27.5
27	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3	28.4	28.5
28	28.6	28.7	28.8	28.9	28.9	29.0	29.1	29.2	29.3	29.4
29	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4
30	30.5	30.6	30.7	30.8	30.9	30.9	31.0	31.1	31.2	31.3
31	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2	32.3
32	32.4	32.5	32.6	32.7	32.8	32.9	32.9	33.0	33.1	33.2
33	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1	34.2
34	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.0	35.1
35	35.2	35.3	35.4	35.5	35.6	35.7	35.8	35.9	36.0	36.1

TABLE 7. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.2-FOOT-HIGH STUMP
"YELLOW" PINE
LINCOLN N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - - - - - - - - - -	D.B.H. IN INCHES	- - - - - - - - - - - -							
5	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9
6	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9
7	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
8	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
9	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9
10	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9
11	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
12	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9
13	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9
14	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9
15	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9
16	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9
17	18.0	18.1	18.2	18.3	18.4	18.4	18.5	18.6	18.7	18.[illegible]
18	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8
19	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8
20	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8
21	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8
22	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8
23	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8
24	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8
25	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8
26	26.9	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8
27	27.9	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8
28	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8
29	29.9	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8
30	30.9	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7	31.8
31	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8
32	32.9	33.0	33.1	33.2	33.3	33.4	33.5	33.6	33.7	33.8
33	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8
34	34.9	35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8
35	35.9	36.0	36.1	36.2	36.3	36.4	36.5	36.6	36.7	36.8

TABLE 8. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
"BLACKJACK" PINE
SANTA FE, CARSON, COCONINO, TONTO N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	D.B.H. IN INCHES									
5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5
6	6.6	6.7	6.8	7.0	7.1	7.2	7.3	7.4	7.5	7.6
7	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
8	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6
9	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6
10	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
11	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6
12	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.5	13.6	13.7
13	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7
14	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7
15	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7
16	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7
17	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.6	18.7
18	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7
19	19.8	19.9	20.1	20.2	20.3	20.4	20.5	20.6	20.7	20.8
20	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7	21.8
21	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7	22.8
22	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7	23.8
23	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8
24	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8
25	25.9	26.0	26.1	26.2	26.3	26.4	26.6	26.7	26.8	26.9
26	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9
27	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9
28	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9
29	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9
30	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9
31	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9
32	33.1	33.2	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0
33	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0
34	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8	35.9	36.0
35	36.1	36.2	36.3	36.4	36.5	36.6	35.7	36.8	36.9	37.0

TABLE 9. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A
1.2-FOOT-HIGH STUMP
"BLACKJACK" PINE
LINCOLN N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - -	- - - -	- - - -	- - - -	D.B.H.	IN INCHES	- - - -	- - - -	- - - -	- - - -
5	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6
6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6
7	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
8	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6
9	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6
10	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
11	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6
12	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6
13	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6
14	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6
15	15.7	15.8	15.9	16.0	16.2	16.3	16.4	16.5	16.6	16.7
16	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7
17	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.6	18.7
18	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7
19	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7
20	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7
21	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7
22	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7
23	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7
24	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7
25	25.8	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7
26	26.8	26.9	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7
27	27.8	27.9	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7
28	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7
29	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7
30	30.8	30.9	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7
31	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7
32	32.8	33.0	33.1	33.2	33.3	33.4	33.5	33.6	33.7	33.8
33	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8
34	34.9	35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8
35	35.9	36.0	36.1	36.2	36.3	36.4	36.5	36.6	36.7	36.8

TABLE 10 -- TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
DOUGLAS-FIR
SANTA FE, CARSON, TONTO N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - -	- - -	- - -	- - -	D.B.H.	IN INCHES	- - -	- - -	- - -	- - -
5	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1
7	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1
8	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.1
9	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1
10	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.1
11	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1
12	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1
13	13.2	13.3	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1
14	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1
15	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1
16	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1
17	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0	18.1
18	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1
19	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1
20	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.1
21	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1
22	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23.0	23.1
23	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0	24.1
24	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0	25.1
25	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0	26.1
26	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0	27.1
27	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1
28	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1
29	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1
30	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9	31.0	31.1
31	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1
32	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1
33	33.2	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1
34	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.1
35	35.2	35.3	35.4	35.5	35.6	35.7	35.8	35.9	36.0	36.1

TABLE 11. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.2-FOOT-HIGH STUMP
DOUGLAS-FIR
LINCOLN N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - - - - - - - - - - D.B.H. IN INCHES - - - - - - - - - - -									
5	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6
6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6
7	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6
8	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6
9	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.4	10.5	10.6
10	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6
11	11.7	11.8	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6
12	12.7	12.8	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6
13	13.7	13.8	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6
14	14.7	14.8	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6
15	15.7	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6
16	16.7	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6
17	17.7	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.6
18	18.7	18.8	18.9	19.0	19.1	19.2	19.4	19.5	19.6	19.7
19	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6	20.7
20	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6	21.7
21	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5	22.6	22.7
22	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5	23.6	23.7
23	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5	24.6	24.7
24	24.8	24.9	25.0	25.1	25.2	25.3	25.4	25.5	25.6	25.7
25	25.8	25.9	26.0	26.1	26.2	26.3	26.4	26.5	26.6	26.7
26	26.8	26.9	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7
27	27.8	27.9	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7
28	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7
29	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7
30	30.8	30.9	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7
31	31.8	31.9	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7
32	32.8	32.9	33.0	33.1	33.2	33.3	33.4	33.5	33.6	33.7
33	33.8	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7
34	34.8	34.9	35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7
35	35.8	35.9	36.0	36.1	36.2	36.3	36.4	36.5	36.6	36.7

TABLE 12. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
ASPEN
SANTA FE, CARSON N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - -	- - -	- - -	- - D.B.H.	IN INCHES	- -	- - -	- - -	- - -	- -
5	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	5.9	6.0
6	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
7	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0
8	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
9	9.1	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
10	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9
11	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9
12	12.0	12.1	12.2	12.2	12.3	12.4	12.5	12.6	12.7	12.8
13	12.9	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.8
14	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8
15	14.9	15.0	15.1	15.2	15.3	15.3	15.4	15.5	15.6	15.7
16	15.8	15.9	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7
17	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7
18	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.5	18.6
19	18.7	18.8	18.9	19.0	19.1	19.2	19.3	19.4	19.5	19.6
20	19.7	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6
21	20.7	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6
22	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5
23	22.6	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5
24	23.6	23.7	23.8	23.9	24.0	24.1	24.2	24.3	24.4	24.5
25	24.6	24.7	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4
26	25.5	25.6	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4
27	26.5	26.6	26.7	26.8	26.9	27.0	27.1	27.2	27.3	27.4
28	27.5	27.6	27.7	27.8	27.9	27.9	28.0	28.1	28.2	28.3
29	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3
30	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3
31	30.4	30.5	30.6	30.7	30.8	30.9	31.0	31.0	31.1	31.2
32	31.3	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2
33	32.3	32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1	33.2
34	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1	34.2
35	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.9	35.0	35.1

TABLE 13. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.0-FOOT-HIGH STUMP
WHITE FIR
SANTA FE, CARSON N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - - -	- - - -	- - - -	- - D.B.H.	IN INCHES	- - - -	- - - -	- - - -	- - - -	- - - -
5	5.3	5.4	5.5	5.6	5.7	5.7	5.8	5.9	6.0	6.1
6	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1
7	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1
8	8.2	8.3	8.4	8.4	8.5	8.6	8.7	8.8	8.9	9.0
9	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.0
10	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0
11	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9
12	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
13	13.0	13.1	13.2	13.3	13.4	13.5	13.6	13.7	13.7	13.8
14	13.9	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8
15	14.9	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8
16	15.9	16.0	16.1	16.2	16.3	16.3	16.4	16.5	16.6	16.7
17	16.8	16.9	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7
18	17.8	17.9	18.0	18.1	18.2	18.3	18.4	18.5	18.6	18.7
19	18.8	18.9	19.0	19.0	19.1	19.2	19.3	19.4	19.5	19.6
20	19.7	19.8	19.9	20.0	20.1	20.2	20.3	20.4	20.5	20.6
21	20.7	20.8	20.9	21.0	21.1	21.2	21.3	21.4	21.5	21.6
22	21.6	21.7	21.8	21.9	22.0	22.1	22.2	22.3	22.4	22.5
23	22.6	22.7	22.8	22.9	23.0	23.1	23.2	23.3	23.4	23.5
24	23.6	23.7	23.8	23.9	24.0	24.1	24.2	24.3	24.3	24.4
25	24.5	24.6	24.7	24.8	24.9	25.0	25.1	25.2	25.3	25.4
26	25.5	25.6	25.7	25.8	25.9	26.0	26.1	26.2	26.3	26.4
27	26.5	26.6	26.7	26.8	26.9	26.9	27.0	27.1	27.2	27.3
28	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.2	28.3
29	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3
30	29.4	29.5	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2
31	30.3	30.4	30.5	30.6	30.7	30.8	30.9	31.0	31.1	31.2
32	31.3	31.4	31.5	31.6	31.7	31.8	31.9	32.0	32.1	32.2
33	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9	33.0	33.1
34	33.2	33.3	33.4	33.5	33.6	33.7	33.8	33.9	34.0	34.1
35	34.2	34.3	34.4	34.5	34.6	34.7	34.8	34.8	34.9	35.0

TABLE 14. - - TREE D.B.H., OUTSIDE BARK, FROM DIAMETER INSIDE BARK AT THE TOP OF A 1.2-FOOT-HIGH STUMP
WHITE FIR
LINCOLN N.F.

STUMP DIAMETER (INCHES)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	- - - -	- - - -	- - - -	- - - -	D.B.H.	IN INCHES	- - - -	- - - -	- - - -	- - - -
5	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4
6	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4
7	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4
8	8.5	8.6	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.3
9	9.4	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3
10	10.4	10.5	10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3
11	11.4	11.5	11.6	11.7	11.8	11.9	12.0	12.1	12.2	12.3
12	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.2	13.3
13	13.4	13.5	13.6	13.7	13.8	13.9	14.0	14.1	14.2	14.2
14	14.3	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.1	15.2
15	15.3	15.4	15.5	15.6	15.7	15.8	15.9	16.0	16.1	16.2
16	16.3	16.4	16.5	16.6	16.7	16.8	16.9	17.0	17.1	17.2
17	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0	18.1	18.2
18	18.3	18.4	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.1
19	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9	20.0	20.1
20	20.2	20.3	20.4	20.5	20.6	20.7	20.8	20.9	21.0	21.1
21	21.2	21.3	21.4	21.5	21.6	21.7	21.8	21.9	22.0	22.1
22	22.2	22.3	22.4	22.5	22.6	22.7	22.8	22.9	23.0	23.1
23	23.2	23.3	23.4	23.5	23.6	23.7	23.8	23.9	24.0	24.0
24	24.1	24.2	24.3	24.4	24.5	24.6	24.7	24.8	24.9	25.0
25	25.1	25.2	25.3	25.4	25.5	25.6	25.7	25.8	25.9	26.0
26	26.1	26.2	26.3	26.4	26.5	26.6	26.7	26.8	26.9	27.0
27	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0
28	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	28.9
29	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9
30	30.0	30.1	30.2	30.3	30.4	30.5	30.6	30.7	30.8	30.9
31	31.0	31.1	31.2	31.3	31.4	31.5	31.6	31.7	31.8	31.9
32	32.0	32.1	32.2	32.3	32.4	32.5	32.6	32.7	32.8	32.9
33	33.0	33.1	33.2	33.3	33.4	33.5	33.6	33.7	33.8	33.8
34	33.9	34.0	34.1	34.2	34.3	34.4	34.5	34.6	34.7	34.8
35	34.9	35.0	35.1	35.2	35.3	35.4	35.5	35.6	35.7	35.8

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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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esearch Note INT-213

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ACQUIRING FOREST INSECT IMPACT DATA

Walter E. Cole, Principal Entomologist

ABSTRACT

Acquisition of pest impact information is a dynamic, continuing phase of management planning. Measurements should include classification of insect effects on individual trees and quantification of the effects on stand characteristics. The evaluation of the net effects of pests as forces of change requires establishment of a base from which changes can be measured. The primary unit of this data base is the forest stand. All measurements and acquisitions of impact data must be accomplished with direct concern for the use (ecological, economics, and social) of the data and in monetary units when possible.

KEYWORDS: impact, acquisition of data, models, use, analysis, and interpretation

Impact is the cumulative net effects of a pest on management activities that ctermine resource uses and values. These effects will range from very good to very td. Consequently, the definition of impact and the way it will be gaged must be explicit in each situation.

The character and reliability of impact information used by pest control supervsors, resource managers, and research directors are entirely dependent upon the aequacy of data collection, data handling, and the analytical and interpretive steps fom which the information is derived. Shortcomings in the scope, quantity, and quality c effort in any of these phases of the system place constraints upon the decisionnking. Constraints cannot be ignored or circumvented, nor can inadequate and abitrarily compiled impact information be accepted.

If impacts of forest pests on current and future timber production are only partally defined, how can economic analyses assess opportunities for optimizing timber poduction and associated benefit/cost returns now or in the future? In fact, if few rlevant data have been taken, how can analyses be made of the direct and indirect efects of pest-caused changes in forest stand composition, density, and structure on wtershed values?

Defensible criteria for decisionmaking on pest control must be stated. For example, studies investigate silvicultural treatments and consequent effects, studies investigate fire incidence and its effects, and studies investigate cause and effect in other functional areas; but, this research often produces little or no tangible recognition of the effects of pests on the ecosystem or management units involved or even of the interactions of pests with the phenomenon or treatment under study.

These considerations imply that evaluating forest pest impacts is an extremely complex task that not only involves identifying and measuring pest effects, but also foreseeing the kind of forest management that will be practiced in the future. Impacts will span the gamut from those that are easily quantifiable to those that are nonquantifiable now.

ACQUISITION

Data acquisition is a particularly dynamic phase in the impact evaluation process. The task of obtaining adequate pest impact information and of bringing it into management planning and decisionmaking is continuing and seems complex. It requires a comprehensive, flexible integrated system with specified data sources and capabilities for handling, analyzing, and interpreting data. However, the basic data needed for measuring impact may not be as complex as they are diverse.

Continual changes in impact criteria and basic analytical technology plus feedback from experience will require corresponding changes, adjustments, and additions to the methodology now available. Measurements should include classification of the direct effects of the impact agent on individual trees and quantification of the effects on stand characteristics. Recording occurrence of specific agents or complexes of agents is an essential complement to tree-stand data. Data on agents may be recorded either by organism or by specific agent-caused effects. Both sorts of data are needed for analysis and interpretation. Surveys will have to be concerned not only with measurement of pest effects in the forest, but also with determination of the present and future management in that particular stand.

Two basic types of management data are needed: (1) ratings of the effectiveness of management strategy and (2) where possible, expected benefits of that strategy in terms of dollar values. Total strategy effectiveness, and the effectiveness of strategy components of that strategy, must be rated qualitatively. The intensity of pest effects that modify effectiveness should be recorded. Ratings of the effectivenss of strategy and of the intensity of modifying factors that can be tabulated by cause in stand tables similar to life tables. The stand tables then could be used to identify losses of management strategy effectiveness by cause. Models for projecting potential effectiveness of the strategy applied at specified ages or age classes could be developed from these stand tables. The objective should be to develop methods of predicting accurately the changes in management effectiveness, given specified intensity of pest activity within specified ages or age classes. Benefit data must then be developed.

There are three basic alternatives to gathering the data:

1. Immediately establish sample plots and take measurements. This could be considered an unacceptable alternative in the context of waiting 30 years to get information that may be needed now.

2. Use exististing historical data. A reasonably accurate base line could be established on a site-to-site basis and effects on stands by major pests could, in part, be established.

3. Combine these two alternatives. Historical data would provide an immediate reliable base from which to work while the addition of new measurements yearly would update and increase the reliability of the base data. The greatest drawback to using historical data is the likelihood of its being in a noncompatible form.

The evaluation of the net effects of pests and other forces of change requires tablishment of a base from which changes can be measured. The primary unit of this ta base is the forest stand. In addition to tree and stand measurements, the data se must include such stand descriptors as cover type or ecosystem, and provenance, d such area descriptors as geographic coordinates. Descriptors are required of the teraction between site and pests and of how they affect stand value. Site descriptors clude soil type, topography, aspects, and productivity. Examples of pest descriptors e the percent of trees infested and the ratings of infestation. The effects of the teraction of these descriptors on such stand values as timber, range, wildlife, and ter should be measured and quantified.

Some individual improvements in data acquisition could be:

1. Expansion of pest survey coverage to include pests of lesser importance, pests fecting noncommercial resource uses, nontimber resource uses, or both, and those sts not currently covered.

2. Extension and improvement of the current system of collecting and processing ta, and improved coordination with complementary activities within other functions d disciplines.

3. Intensification of the specificity of surveys and development of criteria for e precision and accuracy of specifications.

4. Development of uniformity in collection, analyses, and retrieval of data for entral data-control system.

5. Establishment of regular feedback processes and decisionmaking models.

ANALYSIS AND INTERPRETATION

Once procedures for data acquisition and handling are established and systems are veloped, analysis and interpretation of data become keys to successful impact assess- nt. There are three approaches to impact analysis: (1) forest stand tables; (2) tree- -tree models; and (3) aggregate stand models. The analytical techniques applicable each are not exclusive or duplicative; they are complementary. Alone, or more effec- vely, in combination, they will show (1) how and to what extent pests affect the pro- tivity, usefulness, and value of forest stands; (2) how and to what extent pests eract with animals, weather factors, fires, and human uses of the resources; and the relative importance of pests to changes that require modification of management.

Criteria for evaluating forest insect impact must be established. The evaluation uld take into account all noticeable effects and the agents associated with them. simultaneous occurrence of different symptoms, effects, pests, and the association more than one organism with a single effect should be recorded. Past records of pest currence generally have been too restrictive. Often data have been taken on a single or pest and evidence of all others has been kept out of the record, which greatly its analysis and interpretation.

It is necessary to have a frame of reference within which to evaluate any effect, en that the effect has been measured. Also, the effect must be appraised at the e a value is altered. Thus, data for particular stands or locations should encompass ignificant time period, ideally from seeding (or planting) to harvest (or natural ise). Single point-in-time data do not provide the needed information for a complete counting of pest-caused effects. In fact, single records of pest occurrence and re- ed effects may be very misleading.

For example, the value of trees killed by spruce budworm at an early stage of nd development should not be considered a part of the insect's impact. Rather, at time of normal harvest, any difference in value yield from the stand and that from uninfested stand should be the appropriate measure. In some cases, however, the nd that experienced no mortality will require additional money for thinning since y stands are very densely stocked at an early age. Some form of forest management some forest production goals should be implied in setting values. The time of harvest, the desired product, and appropriate stocking require an economic projection if harvest is to be at some future time. These factors all enter into the evaluation process.

In a timber production area, are all trees killed by pests accountable as loss and, therefore, a component of impact? Is real loss, the impact, calculated from some optimal stocking index? Or, is it the difference between net recoverable volume and potential gross volume? Or, more realistically, is it the portion of the net-gross differential that can be recovered now by more effective pest control and in the immediate future by improved technology? In a recreational area where esthetic values are important, is the base line for impact evaluation merely the present condition and appearance of trees and stands or is some lower or higher level of esthetic appeal feasible and justified? Similarly, explicit base lines must be developed for watershed protection, wildlife habitats, and other resource values and uses.

Accuracy and precision specifications must be developed for the various kinds of data taken. The confidence limits will be dictated in each case by (1) the nature of effects and the organisms involved, (2) the techniques used, and (3) the management objectives or value judgments that apply. These same considerations determine the frequency of observations and data recording. It cannot be assumed that generalized specifications will be acceptable for given effects or types of pests. For example, the requirements for accuracy and precision of data, and for the frequency of data collections, would logically differ between an area under intensive management on a 30-year rotation for one objective, an area under intensive management on a 90-year rotation for a different objective, and an area under management for an objective that will not be affected by the pests.

USE

All measurements and acquisitions of impact data must be accomplished with direct concern for the use of the data. Application of models that predict loss of values should yield estimates of net impact, in monetary units where possible. Two levels of programs with the means of establishing priorities. To evaluate pest impact, criteria must be established. These criteria should include the changes in (1) monetary values, (2) production of goods related to resource management objectives, (3) tangible services and (4) intangible services. Other criteria might be selected depending upon the objectives in determining impact.

Models can be used as ways to predict (1) trends in pest numbers, effects, or both; (2) pest population conditions, resource conditions, or both; and (3) the probability of different outcomes from alternative management strategies. Growth projections take into account the effects of pest-caused mortality and growth loss on timber supply and on allowable cut calculations. Numerous analytical procedures can be used to screen management options, including protection against pests. These analytical techniques provide sound reasons for including pest impact data in all decisionmaking. Further, they give the best evidence of the present voids in impact information and of the scope and scale of effort needed to fill these voids.

Finally, we must determine where and how information about the ecological and socioeconomic components of impact come together in the analytical aspects of decision-making. The pathways to action programs and research decisions are different, but they must interrelate. There is feedback at all steps in the system from both research and action programs. This feedback must be developed and used for optimal results. This assessment is necessary to monitor the consequences of human responses to effects of pests. In many instances, the magnitude of the impacts from people-pest encounters is uncertain, and undoubtedly will continuously change as understanding and familiarity with the primary effects increase.

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INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
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EFFECTS OF DIFFERENT TREE PACKAGES VARY WITH SPECIES AND HABITAT TYPES

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ABSTRACT

*The effects of three types of packages (polyethylene-lined kraft paper bag, 2-mil polyethylene bag inside a cardboard box, and open-end, wooden tree crate) on nursery planting stock were tested on two conifer species, lodgepole pine (*Pinus contorta *Dougl.) and ponderosa pine (*Pinus ponderosa *Laws). Crated lodgepole pine trees had highest third-year survival and most height growth for the 3-year study period. Ponderosa pine trees performed best when packaged in polyethylene-lined kraft paper bags. There is some indication that the effects of packaging diminish as handling and planting site conditions approach the optimum for each of these species.*

KEYWORDS: nursery stock, packing media, packaging

Foresters are becoming increasingly aware of the gain in survival and height growth o be expected from improving the quality of nursery stock.

Just as important as developing quality stock is the maintenance of its vigor from ifting to planting on a forest site. In central Idaho, seedlings are often planted on site where soil moisture levels are adequate in the spring (when planting usually takes lace) but decrease until the young trees are under severe stress. To survive this rought period, seedlings must be capable of initiating vigorous root growth soon after lanting.

One factor that may have a pronounced effect on the maintenance of tree vigor is he type of packaging used to hold trees during handling, storage, and shipping.

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[1]Respectively, Forester, Lucky Peak Nursery, Boise National Forest, Boise, Idaho; nd Research Silviculturist located at the Intermountain Station's research laboratory, oise, Idaho.

The two questions addressed in this study are:

1. Which of three packages (polyethylene-lined kraft paper bags, 2-mil polyethylene bags inside cardboard boxes, and open-end wooden tree crates) best maintains tree vigor?

2. Is a particular package best for two of the major species, lodgepole pine (*Pinus contorta* Dougl.) and ponderosa pine (*Pinus ponderosa* Laws.), grown at the Lucky Peak Nursery?

METHODS

The lodgepole pine stock was raised from seed collected in the vicinity of McCall, Idaho, on the Payette National Forest at an elevation of 1,676 to 1,829 meters. The ponderosa pine stock was raised from seed collected on the Boise National Forest at an elevation of 1,524 meters. The age class for both species was 2-0.

Seedlings of both species were lifted, sorted, packaged, and put into storage the first week of April 1972. Until planting time, they were stored at the nursery in a tree cooler where the ambient air temperature ranged from 1.1° to 3.9° C depending largely on outside temperatures.

Trees of each lot were packaged in bags, boxes, and crates on the day they were lifted. The crates were approximately 57 by 19 by 19 centimeters. A strip of Fibreen 200[2] (a waterproofed and fiber-reinforced kraft paper) was used to line each crate. A 4- to 5-centimeter layer of clean, well-moistened sphagnum covered the Fibreen 200. Then alternate layers of moss and seedlings were put into the crate until it was filled. The seedlings were placed root to root in the approximate center of the crate. A final 4- to 5-centimeter layer of moist sphagnum was placed over the roots of the top layer of seedlings and the waterproof paper was gathered at the ends and rolled tightly. The crate was closed with four wire catches.

The seedling bags used were 61- by 28- by 89-centimeter three-ply kraft paper with an inner layer of polyethylene forming the moisture barrier. Two large handfuls of well-moistened sphagnum were placed in the center bottom of each seedling bag. Tree seedlings were placed in layers with their roots over the moss. Two large handfuls of moss covered the roots of the top layer of seedlings. Each bag was closed and rolled tightly to expel the air within it. Then the rolled bag was taped with four strips of 1-inch nylon-reinforced tape.

The seedling boxes consisted of a 17.6 kilograms per square centimeter fiberboard box with a 2-mil polyethylene bag liner. Two large handfuls of well-moistened sphagnum were placed in the bottom center of the liner. Tree seedlings were placed in layers with their roots over moss. Two large handfuls of moss covered the roots of the top layer of seedlings. The liner was closed and rolled tightly to expel the air. Then the box was closed and taped shut with nylon-reinfored tape.

All trees were taken from the nursery to the field in a large cooler built for that purpose. The cooler was an insulated box (approximately 0.9 by 1.5 by 0.6 meters) with an ice retainer in one end. At the planting site, the tree packages were removed from the box and placed in the shade. The tops of the bags and boxes were opened to allow air to circulate as the temperature of the trees increased. Enough trees to plant one plot were removed as needed and placed in a canvas planting bag.

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[2]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

Study plots were established at two locations within the Boise National Forest, Idaho. One site is near Tripod Meadows on the Emmett Ranger District. The study area is on the upper edge of a frost pocket within a large clearcut that was logged in 1970. The habitat type has not been identified with certainty--the sparse understory contains *Vaccinium caespitosum* Michx., but the plots appear to be located on or close to an ecotone between grand fir (*Abies grandis* [Dougl.] Lindl.) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) habitat types. The study area is on a gentle, southwest-facing slope at an elevation of 1,585 meters. The second site is in the Bannock Creek drainage on the Idaho City Ranger District. This study area is within a large clearcut that was logged in 1968. The habitat type is Douglas-fir/ninebark (*Pseudotsuga menziesii*/*Physocarpus malvaceus*). The plots are on a 50 percent slope facing northwest at an elevation of 1,920 meters. Dense shrub vegetation covered the area.

On each study area, five blocks, each containing six 3.4- by 1.2-meter plots, were established in late May and early June 1972. Six treatments were randomly assigned to the six plots in each block:

Species	*Package*
Lodgepole pine	Crate
Lodgepole pine	Box
Lodgepole pine	Bag
Ponderosa pine	Crate
Ponderosa pine	Box
Ponderosa pine	Bag

In each plot, 20 trees were planted in two rows of 10 trees, spaced 0.3 by 0.6 meter apart. All trees were planted in freshly dug 10- by 36-cm auger holes. Special care was taken to prevent air pockets in the planting hole. Before planting was begun, each plot was cleared to mineral soil.

The trees were planted May 26 and 27 at Tripod Meadows and June 5 at Bannock Creek. The time, air temperature, and relative humidity were noted at the time planting began in each block. At Tripod Meadows, air temperature ranged from 12.2° to 17.8° C and relative humidity from 34 to 51 percent. At Bannock Creek, temperatures were higher, ranging from 23.3° to 26.7° C and relative humidities were lower, ranging from 18 to 34 percent.

Live and dead trees were counted and the dominant leader elongation measured to the nearest centimeter at the end of each of the first three growing seasons (1972, 1973, and 1974). The results are presented as survival at the end of 3 years and as height growth for 3 years. Because the sites were widely different, the plantings on the two areas were treated as separate experiments in the statistical analyses. Analyses of variance tests were run on survival and height-growth data. Each percentage value for survival was transformed to arcsin $\sqrt{\text{percentage}}$ prior to analysis. Comparisons among treatment means were made using a sequential method (Snedecor 1956).

RESULTS

Survival.--Unless seedlings were packaged in crates, third-year survival of lodgepole pine was significantly less than that of ponderosa pine on both study areas (table 1). Survival of lodgepole pine ranged from 17 percent for boxed trees on the Bannock Creek study area to 84 percent for crated trees on the Tripod Meadows area. Survival of ponderosa pine ranged from 66 percent for crated trees to 95 percent for bagged trees; both extremes occurred on the Tripod Meadows area.

Table 1.--*Survival and height growth means and statistical significance*[1] *for lodgepole pine and ponderosa pine stored in different types of package*

Species	Package	Tripod Meadows		Bannock Creek	
		Survival	Growth	Survival	Growth
		Percent	*Cm*	*Percent*	*Cm*
Lodgepole pine	Crate	84a	24.0a	68bc	25.6a
	Box	31c	13.0c	17d	14.1c
	Bag	51b	19.1b	43c	22.2ab
Ponderosa pine	Crate	66b	11.6c	73ab	14.2c
	Box	93a	13.2c	88ab	15.9c
	Bag	95a	15.3c	92a	19.5bc

[1] Within any column those values followed by the same letter are not significantly different at the 95 percent level.

We found a significant interaction between package type and species. Survival (fig. 1) was highest for crated lodgepole pine seedlings, lowest for boxed trees, and intermediate for bagged trees. Survival of ponderosa pine was lowest for crated trees and about the same for bagged and boxed trees.

More lodgepole pine trees survived at Tripod Meadows than at Bannock Creek for all three package types. Ponderosa pine survival was about the same on both areas.

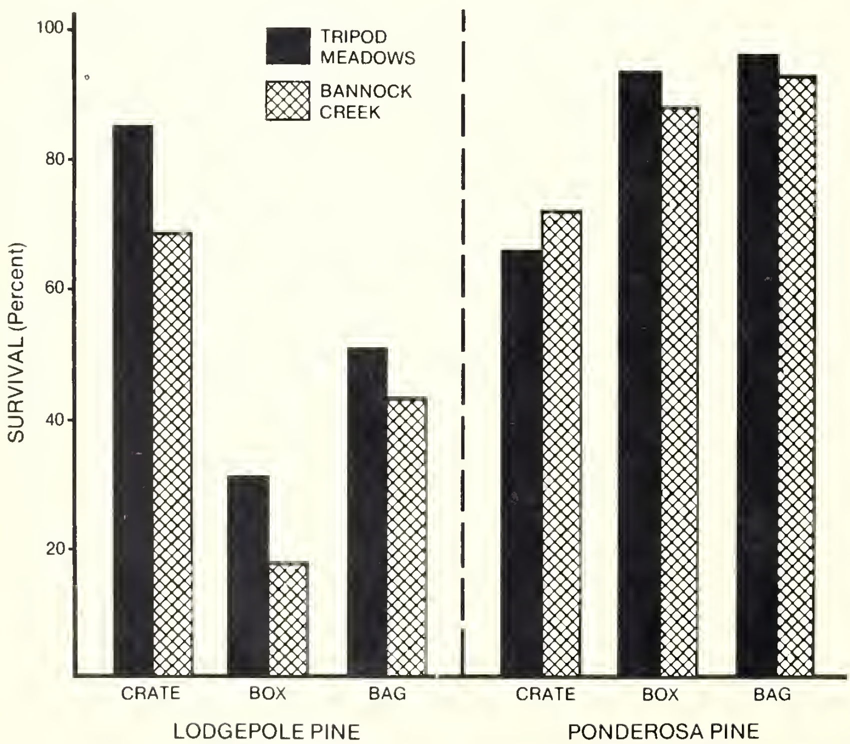

Figure 1.--Third-year survival (percent), lodgepole pine and ponderosa pine.

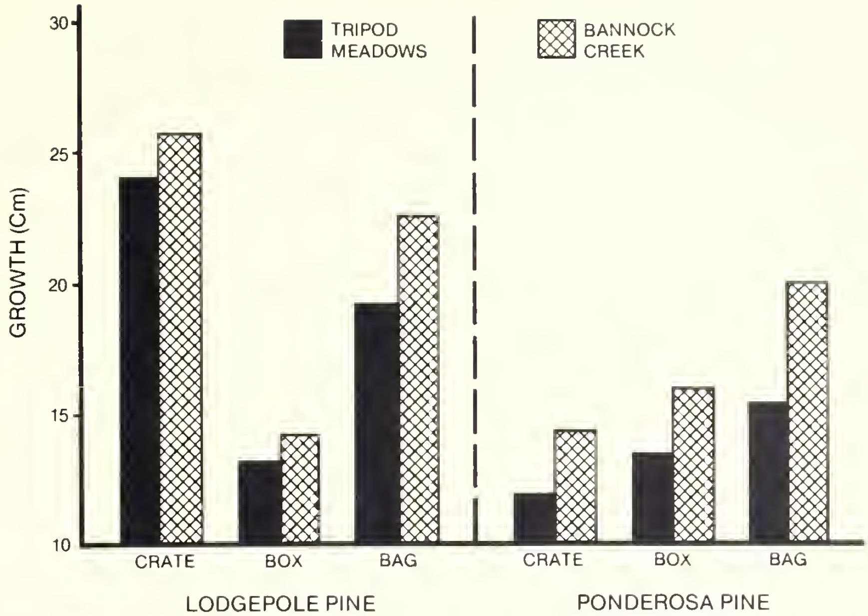

Figure 2.--Three-year growth of lodgepole pine and ponderosa pine.

Height growth.--As is true of survival, height growth is contingent on package type and species (fig. 2). Crated lodgepole pine trees grew more than bagged trees, which grew significantly more than boxed trees (table 1). Crated ponderosa pine trees grew the least and bagged trees the most. However, for ponderosa pine trees in different package types, none of the differences in growth were statistically significant. Trees of both species grew taller at Bannock Creek than at Tripod Meadows, regardless of packaging. Except for boxed trees, lodgepole pine seedlings grew significantly more than ponderosa pine on both study areas.

DISCUSSION AND CONCLUSIONS

Ecological evaluations of the two sites led us to believe that lodgepole pine would perform better at Tripod Meadows than at Bannock Creek and ponderosa pine would do better at Bannock Creek. Our expectations were not fully realized.

On the cold habitat of the Tripod Meadows study area, lodgepole pine is usually the only vigorous timber species found. In fact, the stand removed during logging was almost pure lodgepole. Ponderosa pine was planted offsite on this area. We expected the higher survival of lodgepole pine on this area, but the high survival of ponderosa pine was not expected. We expect the lodgepole pines to develop into well-formed mature trees, but the ponderosa pines may not.

Lodgepole pine is seldom found on the Douglas-fir/ninebark habitat type, but trees planted at Bannock Creek are growing more vigorously than the ponderosa pines.

Lodgepole pine survival is lower than that obtained in subsequent studies or that obtained by Intermountain Region planting projects over the last 3 years. The effects of the package type are also greater than in a more recent study (Morby and Ryker 1975) where each species involved was planted in a habitat where that species grows vigorously.

The poor performance of lodgepole pine could be due to one or more factors. First, the early April lifting date is late for this species. Lodgepole usually begins to break dormancy in February, according to oscilloscope readings (Ferguson and others 1975). Because of the late lifting date, lodgepole pine trees in this study were probably more active and so susceptible to damage and loss of vigor during storage in a closed container. Second, the trees were not acclimatized (Dahlgreen and others 1974). The lack of acclimatization may have affected tree performance, although the high third-year survival of ponderosa pine tends to refute this. Finally, the study reported here was conducted before the refrigeration capabilities of the storage coolers at the Lucky Peak Nursery were improved. Storage temperatures may not have been as constant as they have been since 1972; consequently, the overall vigor of the stored trees might have been reduced while the effect of package type on vigor was increased.

Possibly, the package effects of bags and crates are not significant when trees are lifted early, are properly cared for, and then are planted on sites to which the species is well adapted. However, they quickly become significant when the trees are under stress during handling or after being planted on a site that is severe for the species.

Assuming we are correct, the following recommendations are offered:

Species	*Best package*	*Acceptable package under most circumstances*
Lodgepole pine	Crate	Bag
Ponderosa pine	Bag	Box, crate

For best performance, we recommend the crate for lodgepole pine and the bag for ponderosa pine seedlings. Under optimum care and site conditions, however, either the crate or bag could be used for both species. The box could also be used for ponderosa pine, but the 2-mil polyethylene bag inside the box seemed to give less than adequate gas exchange in this study; many needles exhibited damage that appeared to result from fermentation. We are planning further tests of different types of boxes, and expect that other box designs will give better results.

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Research Note INT-215

February 1977

DELAYED GRAFT INCOMPATIBILITY IN WESTERN WHITE PINE

R. J. Hoff[1]

ABSTRACT

A form of graft incompatibility was observed 11 years after a seed orchard of grafted western white pine was established. After 16 years, over [illegible] percent mortality had occurred in 4 of the 13 clones studied and two more were beginning to show symptoms of graft incompatibility.

KEYWORDS: *Pinus monticola*, graft, incompatiblity, seed orchard

A seed orchard of grafted western white pine (*Pinus monticola* Dougl.) was established in 1959 at Sandpoint, Idaho (Bingham and others 1963). Differences in degree of graft incompatiblity were apparent soon after planting (Hanover 1962). In 1970, 11 years after grafting, additional mortality due to delayed incompatiblity was detected in one clone and, a few years later, in four other clones. This paper describes the symptoms of incompatibility and the extent of damage that occurred in the seed orchard.

MATERIALS

Thirteen trees were chosen as ortets. The selection was based upon the above-average performance of their progeny in resistance to blister rust (caused by *Cronartium ribicola*). Scions were collected in November 1958, packed in snow, wrapped in plastic, and frozen until used.

Stock plants originated from the general white pine population and presumably were susceptible to blister rust. The seedlings were 4 to 5 years old and were established in pots one season prior to grafting.

Grafting was started in January 1959 and was completed in about 3 weeks. The grafts were held in a greenhouse and shade house until planted at Sandpoint, Idaho, in April 1960. Ramet mortality and health were recorded annually.

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[1]Principal plant geneticist, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

OBSERVATIONS AND DISCUSSION

A clear distinction could be made between highly compatible and highly incompatible clones (table 1). Clones 25, 58, 65, and 150 were highly incompatible and eight others were highly compatible. Clone 17 was intermediate between the two groups.

The first signs of delayed incompatibility were expressed a few years after grafting, when differential growth of stock and scion was noted. Two types of abnormal growth occurred. In one case, the scion grew slower than the stock and formed an undergrowth (fig. 1A). In the other type, the scion grew faster than the stock and formed an overgrowth (fig. 1B). Most ramets of three incompatible clones (58, 65, and 150) formed the undergrowth, whereas most ramets of one incompatible clone (25) formed the overgrowth. Besides the trees showing overgrowth and undergrowth at the graft unions, many incompatible grafts showed no noticeable differences in stem diameter at the union. The next visible symptom of incompatibility was a yellowing of the foliage. Foliage yellowed on all trees with incompatible grafts in anywhere from a few months to 2 years prior to death of the tree. When the bark surrounding the graft union was peeled away

Table 1.--*Levels of incompatibility in clones of western white pine grafted in 1959 and observed through 1975*

Clone	Ramets/clone	Dead trees	Yellow trees[1] Nov. 1975	Incompatibility
				Percent
17	96	3	0	3.1
19	53	0	0	0
22	93	0	0	0
24	71	0	0	0
25	63	44	0	69.8
37	36	0	0	0
54	2	0	0	0
58	126	72	24	76.2
63	11	0	0	0
65	83	59	4	75.9
69	29	0	0	0
103	17	0	0	0
150	9	6	1	77.8

[1]Yellow foliage is the first sign of the impending death of the tree. Death usually follows in a few months but sometimes takes place as much as 2 years later.

igure 1.--Differential growth of stock and scion of incompatible grafts of western white pine: A, *Undergrowth;* B, *overgrowth.*

from a tree with yellow foliage, dead or dying bark tissues and pockets of pitch could e seen. Most of the necrotic tissue was in the stock (fig. 2). In every case checked, the stock died first and the scion shortly after.

Graft age determined which type of incompatibility symptoms would appear. An early type showed up soon after grafting (Hanover 1962); so clones were ranked according to scion survival 20 months after grafting. A second type, delayed incompatibility, became visible 11 years after grafting. There was significant clonal variation in the appearance of this symptom. Effects of the reaction were observed in clone 25 in 1970 and in clones 17, 58, 65, and 150 in 1973, 14 years after grafting. The presence or absence of yellow foliage in 1975 reflects this order. Mortality in clone 25 seems to have run its course. Many ramets of clone 19, which appeared to be a compatible clone, now show the undergrowth symptom that is often correlated with graft failure. No other incompatibility symptoms are visible, but the status of clone 19 is questionable.

Delayed incompatibility occurred at about the time trees changed from seedling to adult phenotypes. Delayed incompatibility may be triggered by the aging of root stock. Also, the first big cone crop was produced in 1969, 10 years after grafting, and every year since has been a good cone crop year in the orchard. The added stress of a cone crop could have triggered delayed incompatibility.

These results indicate that seed orchards of grafted western white pine are subject to considerable loss because of graft rejection. One possible way to partially circumvent the problem would be to graft fewer ramets per clone and include many more clones in the orchard. Another possibility would be to develop highly graft-compatible root stocks, as is now being done for Douglas-fir (Copes 1973).

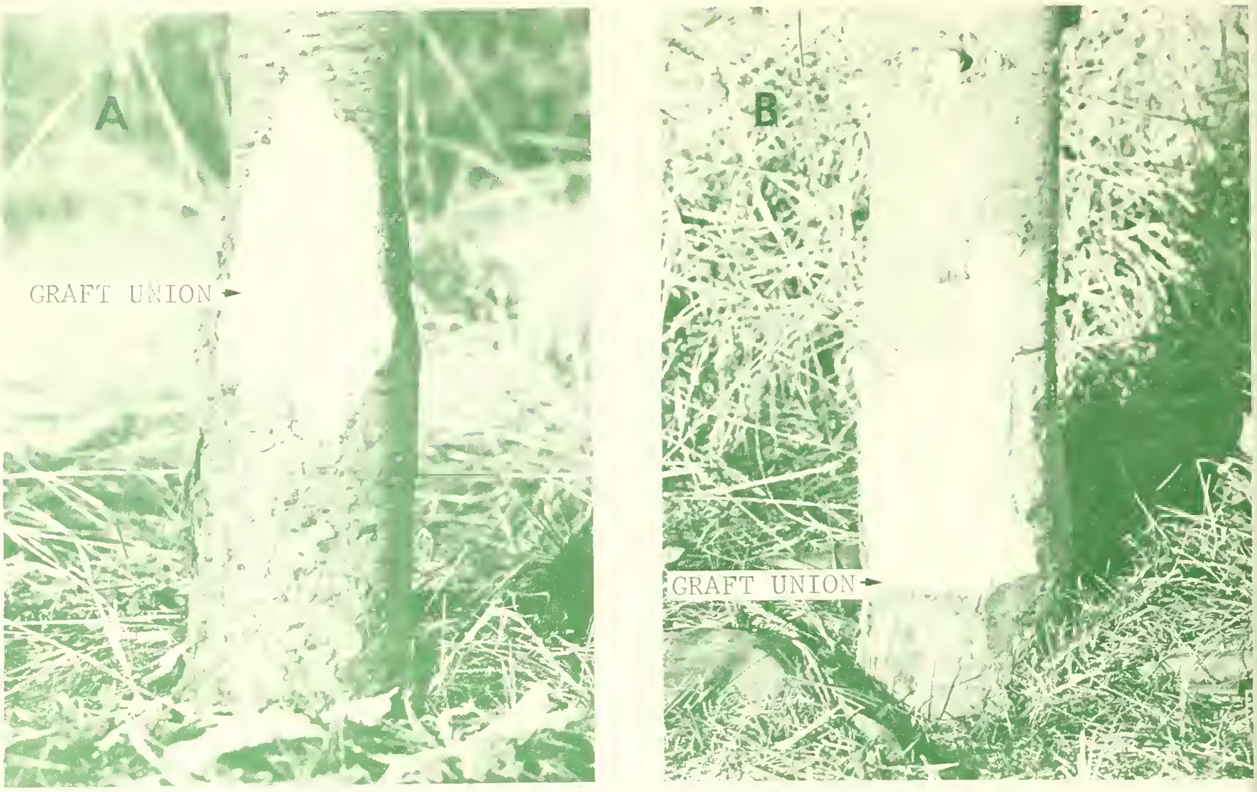

Figure 2.--Graft unions with bark removed: A, Compatible graft with slight undergrowth, graft union not visible; B, incompatible graft clearly showing graft union. Outer bark layers have been removed revealing dead cortex, phloem, and cambium tissues.

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PROTECTING AND STORING INCREMENT CORES IN PLASTIC STRAWS

Dennis M. Cole[1]

ABSTRACT

Percent shrinkage of lodgepole pine increment cores sealed in plastic drinking straws and stored for varying periods up to 31 days was compared to the method of soaking air-dried cores to restore their dimensions. Instructions are given for sealing straws with tape and recommendations made for various situations when original dimensions cannot be measured at time of core extraction.

KEYWORDS: increment core shrinkage, increment core storage

For years drinking straws have been used to protect increment cores being transported from field to office, and to store cores for later measurement. Usually, the core is placed in the straw and the ends folded and crimped to confine the core. This does not protect the core from drying and shrinking; therefore, cores must be soaked in water to restore them when original dimensions are important (Brace 1966). Although effective, soaking is troublesome and may not be necessary.

I find that plastic straws, properly sealed with cellulose-acetate tape (one brand is Scotch Magic Transparent Tape[2]), protect cores from shrinkage for several days (paper straws are less effective and are now nearly unobtainable). Following is the method for sealing the straws, and the results of tests illustrating effectiveness of the method.

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[1]Research Forester, located at the Intermountain Station's Forestry Sciences Laboratory, Bozeman, Montana.

[2]Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

STRAW SEALING METHOD

Seal one end of straw with 3/4-inch-wide, cellulose-acetate tape, by wrapping a strip of tape around approximately 3/8 inch of the end of the straw to form an extended tape tube, then firmly pressing together the adhesive inner surface of the tube to form a flattened tab. Draw the tab (especially the edges) between the thumbnail and first finger to insure seal. Immediately upon extraction from the tree, insert the core into the prepared straw and seal the open end as above. To accommodate cores longer than the common 8¼-inch plastic drinking straw, join straws by slightly flaring the end of one straw with the tapered end of a pencil and firmly insert another straw into the flared end. The connection should be wrapped with the cellulose-acetate tape. The straw can be labeled by marking the tab with a ballpoint pen or pencil (other types of moisture resistant tape can be used, but to my knowledge, only the cellulose-acetate tape can be marked with pen or pencil).

A TEST METHOD

Increment cores were taken from 24 lodgepole pine trees growing in the Gallatin National Forest near Bozeman, Montana, in August 1975. Immediately upon extraction, cores were placed in a precision jig and marked at 0.500 and 4.000 inches from the cambial surface (accuracy ±0.002 inch to determine if the more recent wood (sapwood) might shrink more than the older wood (heartwood). Cores were placed in plastic straws and sealed with cellulose-acetate tape as described; then randomly divided into two groups of 12 straws each, to test the effectiveness of the tape seal under 3-day and 21-day office storage. At the end of each storage period, the appropriate straws were opened and the marked segments on each core were immediately measured to the nearest 0.001 inch.

To provide a basis for comparison, the cores were allowed to air-dry for several weeks under office conditions; then a random sample of 12 cores was drawn and soaked in water for 30 minutes, and the marked segments measured after soaking. The results are summarized in table 1.

Percent shrinkage in the straws was greater in 0.500-inch segments (representative of sapwood) than in the 4.000-inch segments (representative of heartwood), but was significantly greater only for the 21-day storage period. The greater percent shrinkage in the 21-day storage versus the 3-day storage was statistically significant for both 0.500-inch and 4.000-inch segments.

Table 1.--*Original length, shrinkage after two storage periods in sealed straws, and shrinkage remaining after soaking for 12 increment core segments.*[1]

Original length of core segments	3-day storage		21-day storage		Shrinkage remaining after 30-minute soaking treatment	
Inches	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*
0.500	0.007	(1.4)[a]	0.016	(3.2)[b]	0.000	(0.0)
4.000	.008	(.2)[a]	.049	(1.2)[c]	.012	(.3)

[1]Percentages having different letter superscripts are significantly different at 0.05 level (diagonal comparisons not intended).

The sealed straw treatment protected the cores from significant shrinkage for the 3-day storage period for both the short and long core segments. The maximum shrinkage over this period (0.008 inch) is considered less than the measurement error incurred when measuring cores with hand-held rulers (regardless of the fineness of their graduations)--especially when no optical magnification is used.

The 3-day, sealed straw treatment gave better results than 30-minute water soaking for the 4.000-inch segments which represent situations where the heartwood or total core length is of interest. In this dry climate, the 30-minute water soaking is not long enough to restore air-dried heartwood of lodgepole pine increment cores.

A possibly detrimental effect of the sealed straw method was the growth of fungus on some cores sealed for 21 days. Although not a problem in this case, fungi could prove detrimental in identifying and measuring closely spaced annual rings.

A further improvement on the sealed plastic straw method is to freeze the cores after sealing them inside the plastic straws to maintain dimensions and prevent fungus growth. In an independent test of 10 lodgepole pine increment cores, no measurable change in length occurred in the cores during 3 days of freezer storage. Apparently, cores can be kept fresh for long periods, if frozen within a short time after being sealed in plastic straws.

RECOMMENDATIONS

From the above results, the following recommendations are made:

Core storage time	*Core storage method*
<1 day	unsealed straw
1-3 days	sealed straw
>3 days	sealed and frozen straw

When a freezer is not available and storage longer than 3 days is required, increment cores should be allowed to air-dry (but should be stored in unsealed straws for protection) and later soaked in water (at least 1-1/2 hours soaking is recommended for the drier western conditions) to restore their lengths.

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JSDA Forest Service
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A SOIL SAMPLER FOR STEEP, ROCKY SITES

M. F. Jurgensen, M. J. Larsen, and A. E. Harvey[1]

ABSTRACT

A portable, hand-operated soil core sampler has been developed for sampling soils on steep, rocky sites. The sampler provides a 10- by 30-cm (4- by 11.8-in) soil core and can be built by most machine shops. Construction drawings and material specifications are available from the Forest Products Laboratory, Madison, Wisconsin 53705.

KEYWORDS: soils, soil core sampler

Forestry-related studies commonly require the collection and analysis of soil samples. To minimize disturbance to the samples, the soil sampler and the sampling technique should be adapted to the physical properties of the soil. Sampling methods developed include hand-operated samplers, explosive-charged devices, and machine-driven, tractor-mounted units (Hayden and Robbins 1975; Schickedanz and others 1973; McIntyre and Barrow 1972; Hayden and Heineman 1968).

In soils where rocks or large roots are numerous, dug pits or power-driven soil samplers have been recommended (Hoover and others 1954). However, in some areas stone makes digging impractical. Steep, rugged terrain may prevent the use of heavy, power-driven equipment. Both conditions are common in many areas of the Intermountain West.

A study on the environmental effects of timber harvesting practices on steep, rocky sites in western Montana required taking large numbers of soil samples. In conjunction with the Forest Products Laboratory, Madison, Wisconsin, a new, hand-operated soil sampling device was developed which solved many of the problems in sampling the soil in this steep, forested area (fig. 1). This new soil sampler (called the "Thumper") has two basic units: (1) a soil-coring cylinder, and (2) a combination cylinder driver and soil core extractor. Parts and operation of the device are shown in figure 2.

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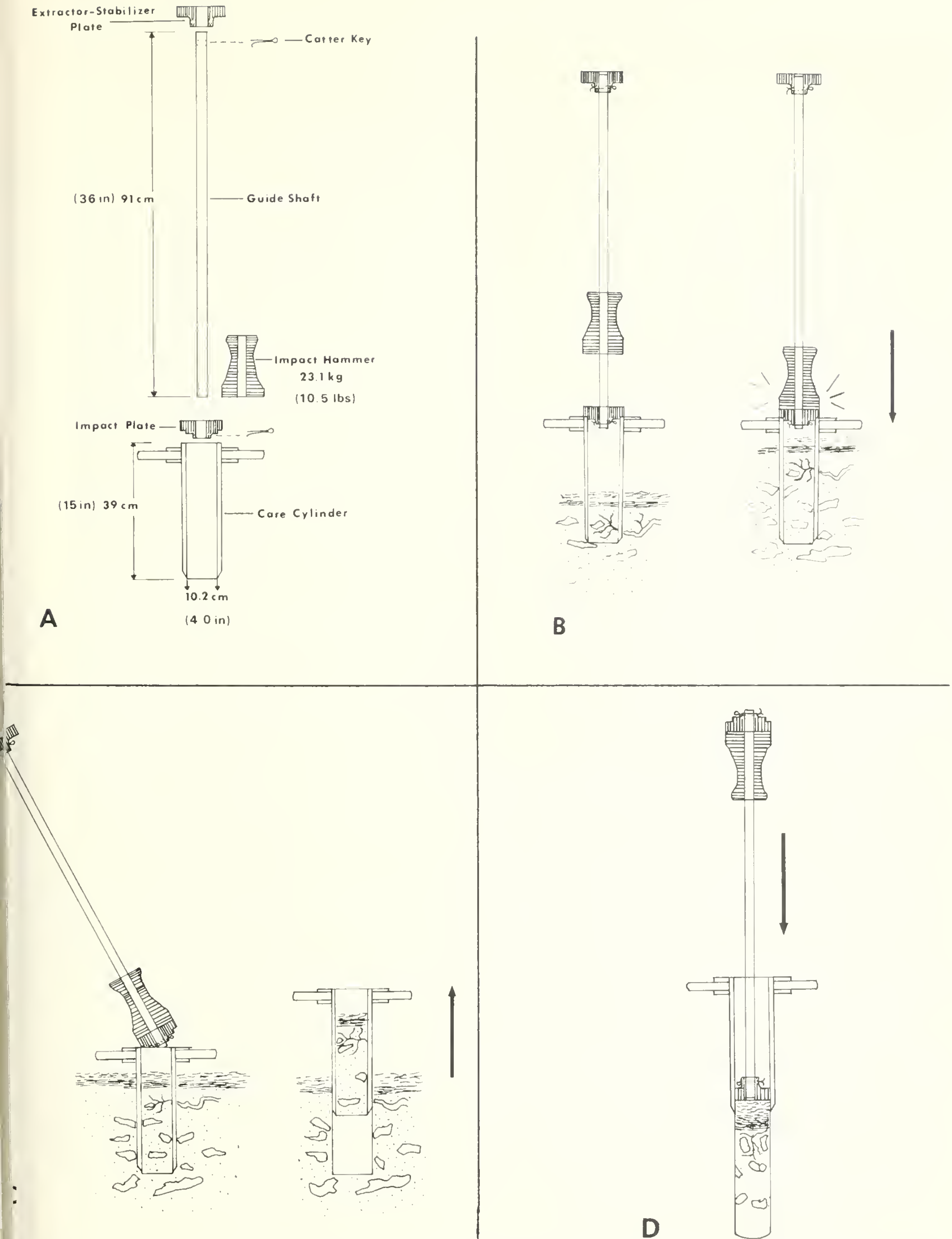
[1]Respectively: Associate Professor of Forestry, Michigan Technological University, Houghton, Mich.; Mycologist, Forest Products Laboratory, Madison, Wis.; and Plant Pathologist at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

The authors are indebted to all those forestry technicians who used the sampler in the field and made substantial recommendations on use and design. Special thanks are accorded Mr. R. V. McCall, Foreman of the Metal Working Shop, and Mr. A. L. Koster, Supervisory Mechanical Engineer, both of the Forest Products Laboratory, for their patience, understanding, and efforts. Appreciation is extended to Ms. Patricia Howe for providing illustrative material.

Figure 1.--Crew operating soil sampler. One man (right) holds device perpendicular to slope, the other drives core cylinder into ground with sliding hammer.

The success of the sampler is attributed to its engineering design, solid construc tion, and strength of component materials. Although the unit weighs nearly 18 kg (40 lb), it can be carried by one person. Initially, the bottom impact plate and top soil core extractor plate (fig. 2A) were welded to the guide shaft of the impact unit. However, the force, 2,100 kg/cm^2 (approximately 30,000 psi), and vibrations generated within the shaft and plate units during operation frequently broke the welded joints. This problem was corrected by attaching both plates to the shaft by large cotter pins. The pins shear occasionally, but are easily replaced in the field. The use of removabl pins also allows the impact unit to be disassembled and carried in a backpack, an impor tant factor when walking long distances to sampling points.

The cutting edge of the coring cylinder eventually becomes dulled and chipped after repeated use. However, it is easily sharpened with a grinding wheel or a hand file. Because the weight generates a loud, high-frequency noise on impact, the crew should protect their hearing with earplugs or similar devices, especially if numerous samples are to be taken.



'igure 2.--*Components and operation of soil sampler:* A, *Sampler assembly;* B, *driving coring cylinder into ground;* C, *pulling cylinder from soil;* D, *extracting soil sample.*

Figure 3.--Soil sample after removal from coring cylinder.

SAMPLING PROCEDURE

Use of the "Thumper" soil sampler usually requires two people--one to drive the impact weight, the other to hold the impact unit on the core cylinder. The cylinder is driven into the soil, rotated one-half turn, then carefully removed. The soil core is pushed out by means of the extractor plate at the end of the impact unit. The soil core can be handled as one unit (fig. 3) or divided by horizon or depth for transport to the laboratory.

In the past 2 years, more than 2,000 soil cores (rock content from 40 to 75 percent) have been taken from steep, rocky terrain with samplers of this design (Harvey and others 1976). A two-person crew can collect up to 50 cores per day. However, the limiting factor in the sampler use is not taking soil cores, but removing them from the site. Assuming a soil bulk density of 1.3 g/cc, each core weighs approximately 3.2 kg (7 lb).

SAMPLER SIZE

The core cylinder size used for most studies was 39 by 10.2 cm i.d. (15 by 4 in) hich gives a maximum soil sample volume of approximately 2,500 cc (152.5 in^3). A core nit of these dimensions was selected since it approached the sample size recommended y Usher (1970) for determining soil nutrient levels. However, sampler size can be aried depending on the objectives of the study. A scaled-down version having a core ylinder of approximately 20 by 6 cm (8.3 by 2.5 in) was found to work satisfactorily f the rocks were not large.

The 39 by 10 cm "Thumper" unit costs about $200 and can be fabricated in most achine shops. Construction drawings and materials specifications for the "Thumper" mpact soil sampler are available from M. J. Larsen, Forest Products Laboratory, adison, Wisconsin 53705.

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Selecting Western White Pine Leave-Trees

Leave-Tree

USDA Forest Service
Research Note INT-218
April 1977

BLISTER RUST CONTROL

White pine blister rust infects nearly al western white pine in Idaho, eastern Wash ington, and western Montana, and has kille up to 95 percent of the white pine in loca tions most favorable to the rust.

Presently, the only control available is t use blister rust-resistant planting stock More than 300 pounds of sound seed ha been produced at the Sandpoint seed orchar and Moscow arboretum through the 197 seed year. All needs for resistant plantin stock will soon be satisfied. But how ca present stands be managed? It is desirabl to leave some white pine in a stand becaus it may be the "best" tree for the site, an the progeny of the surviving trees will ex hibit increased resistance to blister rust.

The probability of managers selectin the more resistant individuals to produc the next generation is very high if an ex haustive blister rust survey were complete for each stand. But a method that is les time consuming is needed. Since the amoun of mortality varies directly with the amoun of blister rust present and the rate of mor tality varies indirectly with the age of th trees, several approaches are needed.

Young Stands (less than 30 years old)

Leave trees that have no stem canker and relatively few branch cankers. Designat leave-trees after a rapid visual inspection a the site, without counting cankers.

Trees to be Removed

Pole Stands (30-60 years old)

Cankers in these stands are difficult to see, but the resistance in the stand has had many years to be expressed. Hence, we propose that selection of leave-trees be based solely on crown appearance.

Ignore blister rust stem cankers and branch flags, and leave-trees that have dense, luxuriant, grass-green foliage (see front and back panels of this note). Seven years' accumulation of data from stands in which nearly every tree of this type had cankers shows that these trees have a very low mortality probability (1.1 percent per year).

Trees to be removed exhibit a sparse, gray-green foliage and generally appear unthrifty. Seven years' accumulation of data shows that trees of this type exhibit a high probability of mortality (7.3 percent per year).

Mature Trees (more than 60 years old)

Trees in these stands have reached merchantable age. If the stand is to be regenerated by seed tree or shelterwood methods, leave disease-free, fast-growing, best-formed trees. Selection is most easily accomplished if it is done in two stages.

First, mark and remove all the obviously poor trees. Then, select the leave-trees from those remaining. Stands that have had 80-90 percent mortality should yield 20 percent resistant progeny. If the leave-trees are average seed producers, each tree will produce 335 established seedlings over a 5-year regeneration period, and if 10 white pine seed trees remain per acre, the new stand (3,350 trees per acre) can suffer 80 percent blister rust mortality and still be considered an established stand (670 trees per acre).

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Leave-Tree

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ATTRITION OF LODGEPOLE PINE SNAGS ON THE SLEEPING CHILD BURN, MONTANA

L. Jack Lyon[1]

ABSTRACT

Following 2 years with little windthrow, snags on the Sleeping Child Burn fell at an annual rate of 13.4 percent. Snags less than 3 inches d.b.h. fell at a rate of 27.9 percent and nearly all were down in 15 years. Snags larger than 3 inches fell at an annual rate of 8.4 percent, but those larger than 8 inches fell sporadically. At current rates, all snags will fall within the next 40 years; however, a few larger snags with a lower probability of windthrow will stand indefinitely.

KEYWORDS: fire effects, salvage logging, windthrow, snag fall

The rate at which snags fall is of interest to land managers for a number of reasons. Drying checks may reduce the value of snags for sawtimber (Mielke 1950), but ". . . the actual loss by direct burning is seldom more than 3 percent of the gross volume" (Boyce 1961). As long as they remain standing, snags represent some real or potential value for pulpwood, house logs, firewood, and wildlife habitat. Standing snags may also increase the hazard of lightning-caused fires but, once on the ground, snags increase the fuel load and become subject to discoloration and decay.

As a part of a study of postfire vegetal succession on the Sleeping Child Burn, Bitterroot National Forest (Lyon 1976), I examined snag attrition by periodically counting the number of standing snags on eight transects located at elevations between 6,400 and 7,200 feet within the 28,000-acre burn. Each transect consisted of 10 permanently located circular plots, 23.55 feet in radius (0.04 acre), spaced at 50-foot intervals.[2] Standing snags were recorded in four diameter (breast high) classes: under 3, 3 to 8,

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[2]Conversion to metric units requires the following constants:

Acres X 0.405 = hectares
Feet X 0.305 = meters
Density/acre X 2.471 = density/hectare
Inches X 2.540 = centimeters

8 to 12, and over 12 inches. Initial data were taken 1 year after the fire in 1962, and counts were repeated in 1963, 1966, 1969, 1971, and 1976.

Snag species were not recorded, but lodgepole pine *(Pinus contorta)* was the dominant tree species. In general, stems under 3 inches in diameter were subalpine fir *(Abies lasiocarpa)* and all others were lodgepole pine with the exception that the few very large snags (over 12 inches) were Douglas-fir (*Pseudotsuga menziesii*) and Engelmann spruce (*Picea engelmannii*).

RESULTS

Postfire snag densities ranged from 240 to 918 stems per acre on the eight sample transects (table 1). There was no way to identify snags that remained standing during the fire and then fell before the first count in 1962. However, I have assumed that most of the initial fall did occur during or immediately after the fire and that the 1962 average of 497 snags per acre was representative of initial snag densities in 1961. Confirmation of an extremely low attrition rate for at least 2 years was also suggested by the just over 1 percent loss between 1962 and 1963.

After the second postfire year, snag fall increased substantially. Nearly half of all snags had fallen by the fifth season, and only 28 percent were standing in the 10th year. After 15 years, barely 15 percent were still standing (table 2). The average annual attrition rate for the last 13 years of the study was 13.4 percent, but this result is somewhat misleading because snags under 3 inches had a much higher rate than larger stems (fig. 1). (Attrition rate, as used in this paper, is the annual percentage loss of snags upright at the beginning of the year. A 10 percent annual attrition for 10 years would leave nearly 35 percent of the original stems still standing.) While only 1.4 percent of the small snags remained standing in 1976, over 30 percent of the snags greater than 3 inches in diameter were still upright.

Attrition rates for small snags were relatively consistent among transects and constant through the years. After two seasons of less than 1 percent annual loss, snag fall averaged 27.9 (18 to 33) percent of those still standing each year for 13 years. Snags 3 to 8 inches in diameter also had a constant, but far lower, attrition rate of 8.4 (6 to 10) percent after the initial 2 years of minor loss. For snags over 8 inches, these data suggest a somewhat less predictable pattern. Following 2 years of about 2 percent annual windthrow, attrition averaged 8.6 percent for 13 years. However, fall of snags over 8 inches was sporadic rather than constant. Because data were not taken annually, I cannot confirm large windthrow in any single year, but the alternating periods of high and low attrition suggest a possibility of 20 to 30 percent windthrow mixed with years of almost no loss.

Table 1.--*Numbers of snags per acre on each of eight transects by year of count*

Transect	Year 1962	1963	1966	1969	1971	1976
SC01	498	498	393	343	333	258
SC02	390	383	188	160	123	73
SC04	423	413	190	145	110	68
SC08	240	240	148	83	38	15
SC09	693	685	403	268	203	75
SC10	918	918	358	160	95	28
SC11	570	565	265	170	108	35
SC12	243	223	198	160	118	53
Average	497	490	268	186	141	75

Table 2.--*Average number of snags per acre by size class and year of count. (Totals may not agree because of rounding.)*

Size class (inches)	Year 1962	1963	1966	1969	1971	1976
Under 3	266	265	96	41	28	4
3 to 8	159	156	124	103	85	50
8 to 12	64	62	40	36	24	19
Over 12	7	7	7	6	4	3
Total	497	490	268	186	141	75

For all snags over 3 inches in diameter, average annual attrition on different transects ranged from 1.4 to 14.7 percent. The number of samples available is considered inadequate to justify a definitive conclusion, but there is some suggestion that windthrow probabilities are slightly lower on northerly aspects (transects 1 and 4) and at higher altitudes (transects 1 and 2). There was no indication that slope or snag densities influenced windthrow rates.

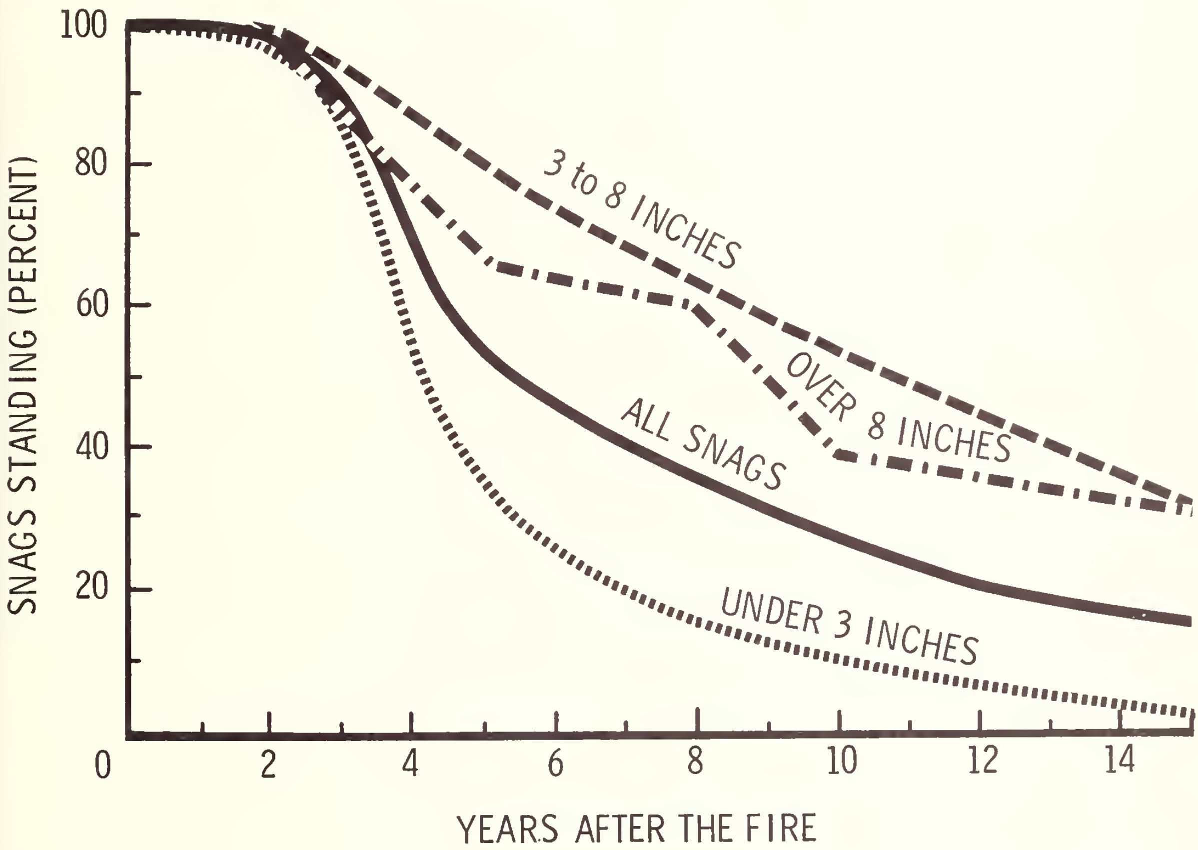

Figure 1.--Percentage of snags still standing, by year and diameter class, Sleeping Child Burn, 1962-1976.

DISCUSSION

Two previous papers on snag deterioration have described decay and windthrow of merchantable beetle-killed Engelmann spruce (Mielke 1950; Hinds and others 1965). In both reports, the majority of stems were of larger diameter than the snags on the Sleeping Child Burn. However, these studies were also done in high altitude forests, and some comparisons are thus possible.

Mielke (1950) counted Engelmann spruce in Utah and found that only 16 percent had dropped after 25 years. For stems 3 to 7 inches in diameter, annual attrition was 0.92 percent and for snags greater than 8 inches annual attrition was 0.69 percent. Another paper (Hinds and others 1965), from Colorado, shows annual attrition of 5-inch and larger Engelmann spruce ranging from 0.6 to 2.5 percent for periods up to 23 years. This paper also reports one sample of beetle-killed lodgepole pine with an annual attrition below 2 percent for 17 years. Average diameter of these snags was 12 inches, which may partially explain the low attrition rate as compared to the smaller snags on the Sleeping Child Burn. However, it is also logical to propose that snag attrition rates in fire-killed timber are inherently higher because there are no live trees remaining to reduce wind velocities.

SUMMARY AND CONCLUSIONS

Following 2 years with very little windthrow, snags on the Sleeping Child Burn fell at an annual rate of 13.4 percent. Snags less than 3 inches in diameter had an almost constant attrition rate of 27.9 percent and were virtually gone in 15 years. All snags larger than 3 inches fell at an annual rate of 8.4 percent, but stems larger than 8 inches seemed to fall sporadically rather than at a constant rate. At the current rate of attrition, all snags on the burned area will fall within the next 40 years. However, because larger snags have a lower probability of windthrow, a few will stand indefinitely.

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RESPONSE OF PONDEROSA PINE SEEDS TO LIGHT

Michael Harrington[1]

ABSTRACT

Rates and percentages of germination of one race of ponderosa pine seeds were increased by a 24-hour light treatment compared to seeds kept in the dark. For seeds that had undergone 0 or 7 days of stratification, red light appeared to promote germination, whereas far-red light appeared to inhibit germination. Twenty-one days of stratification essentially removed these light responses, but increased germination over seeds with less stratification.

KEYWORDS: ponderosa pine, seed germination, light, moisture, stratification

Ponderosa pine forests have been characterized as large, uneven-aged stands composed of small even-aged groups in various stages of maturity (Weaver 1943). The small groups were the result of a single year of germination in openings within the stand. Cooper (1961) also observed the almost exclusive occurrence of pine reproduction in clearings between large overstory trees or groups of trees. Similarly, in western Montana, ponderosa pine seedlings rarely exist beneath the heavy canopy cover of the more mature trees. This may be the result of limited moisture, nutrients, and sunlight. There is also the possibility that many seeds never germinate.

The ability of a ponderosa pine seed to germinate is influenced by a complex of environmental factors. Proper combinations of temperature, moisture, and oxygen are critical. In addition to and interacting with these factors, light might be important.

Although seeds of many species of trees and shrubs frequently become buried and germinate without light, others require light stimulation. *Pinus palustris* seeds germinate better in light than in darkness as do seeds of *Pseudotsuga menziesii* and *Pinus banksiana* (USDA Forest Service 1974). Most seeds must be moist at the time of exposure to light if the light is expected to influence germination. *Pinus sylvestris* is an exception because germination is increased by light exposure even when the seeds are dry (USDA Forest Service 1974).

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[1] Michael Harrington conducted the experiments described here at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana, where he worked as a technician, 1973-1975. He received his M.A. in botany from the University of Montana in March 1977.

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Germination of some species of seeds is affected not only by light quantity but also light quality. Red light may promote germination whereas far-red light may inhibit germination. Conifer seeds that respond in this manner are *Abies veitchii, Abies homolepsis, Picea glehnii, Pinus thunbergiana,* and *P. sylvestris* (USDA Forest Service 1974). Other pines that are also influenced by light quality are *P. palustris* (McLemore and Hansborough 1970), *P. virginiana* (Toole and others 1961), *P. taeda* and *P. strobus* (Toole and others 1962), and *P. banksiana* (Orlandini and Buland 1972).

Within the seed a pigment called phytochrome is thought to absorb and interpret light energy. Hendricks and others (1956) assume the reaction is as follows:

$$\underset{\text{(Red adsorbing)}}{\overset{\text{(Seeds dormant)}}{\text{Pigment 1 + Reactant A}}} \underset{\text{Far-red}}{\overset{\text{Red}}{\rightleftharpoons}} \underset{\text{(Far-red adsorbing)}}{\overset{\text{(Seeds germinating)}}{\text{Pigment 2 + Reactant B}}}$$

Pigment 1 has the capacity to absorb red light and is converted to pigment 2. Pigment 2 reacts with reactant B to break dormancy (increase respiration and mitosis). However, if far-red light is absorbed by pigment 2 before germination occurs, it will be converted back to pigment 1 which reacts with reactant A to revert the seed back into a state of dormancy.

Working with *Pinus sylvestris,* Kopcewicz and Porazinski (1973a, 1973b) found that an increase in germination due to either stratification or red light treatment corresponded to a simultaneous increase in gibberellin content. Because this pine has been shown to respond to the red and far-red light treatments, red light may cause an increase in gibberellins, known to be germination promoters and a decrease in abscisic acid, known to be a germination inhibitor.

Three experiments involving the effect of light on ponderosa pine seeds were performed to determine if seed germination (1) is light dependent (photoblastic), (2) is affected by varying red and far-red light densities, and (3) follows the photoreversible phytochrome response. The experiments followed the design of Toole and others (1961) and McLemore and Hansborough (1970).

GENERAL PROCEDURES AND MATERIALS

The seeds used for these experiments were collected in the fall of 1974, 40 miles northeast of Missoula, Montana, in a Douglas-fir--pine grass habitat type. They were stored in a moistureproof container at 3°C. Before the experiments, the seeds were placed into a beaker of n-pentane, which separates viable seeds from those with empty seed coats and dried embryos.

Red and far-red light were produced by modifying a method used by Poff and Norris (1967). Red light with a maximum wavelength of 650 nanometers (nm) was produced by shining a bank of nine 750-watt flood lamps through 6 cm of 1 percent cupric sulfate solution and two red filters. Far-red light with a maximum wavelength of 750 nm was produced by passing the light from nine 750-watt flood lamps through 6 cm of a ferrous ammonium sulfate solution and two far-red filters separated by the Cinemoid component from a blue filter. Light intensity was measured with an Eppley pyrheliometer. The intensities of both the red and far-red light were nearly equal, reaching levels of between 4,500-5,000 erg/cm^2/s.

Before and after light treatments the seed containers (petri dishes) were wrapped in foil to prevent exposure to other light. Germination took place in a growth chamber set at 25°±2°C. Germination was observed at frequent intervals under a safe, green light. A seed was considered germinated when the radicle protruded about 2 mm and turned down. As seeds germinated they were removed. When the experiments were terminated, both percent germination and germination values were computed. The germination value is a measure of both completeness and speed of germination. It is calculated by multiplying the mean daily germination rate by the highest daily germination rate (McLemore and Czabator 1961). Transformation of the germination data was not deemed necessary because of the narrow range of germination percentages within each experiment and variance homogeneity.

EXPERIMENT 1

PROCEDURES

This experiment was to determine if ponderosa pine seed germination is light dependent (photoblastic). Fifty seeds were placed in each of eight 9-cm petri dishes. Four of the dishes had sponges saturated with distilled water. The other four had no sponges or water. The petri dishes were placed in a dark chamber set at 25°C for 24 hours. This procedure allowed half of the seeds to imbibe water. Following the imbibement period, half of the imbibed seeds and half of the dry seeds were exposed to 23 hours of white light from two fluorescent tubes, and 1 hour of red light. The other seeds were kept in the dark. Following the light treatments, half of the seeds from all treatments were removed for moisture content determination by drying at 105°C for 24 hours. The remainder was placed on moist sponges in petri dishes which were wrapped in foil and placed into the germination chamber. Germination was allowed to continue for 21 days.

RESULTS

The imbibed seeds had about 5 times the moisture content of the dry seeds. Regardless of light treatment, the imbibed seeds had moisture contents which ranged from 39.8 to 43.8 percent. The range of moisture for the dry seeds was from 8.1 to 8.7 percent. The percent germination and germination values along with the results of the factorial analysis of variance tests are shown in table 1.

Both percent germination and germination values of imbibed seeds, regardless of light treatment, were greater than for dry seeds, the difference being highly significant. Light-treated seeds also had higher germination values and percentages than seeds treated with no light, but the differences were not great. Variances were homogeneous in all cases.

Table 1.--*Effect of light and moisture on percentage of germination and germination value of ponderosa pine seeds*

	Percent germination±S.D.		Germination values±S.D.	
	Light	Dark	Light	Dark
Imbibed	51.0±6.0	43.0±8.2	13.17±6.73	7.89±2.81
Dry	34.0±8.3	24.0±11.3	4.04±1.71	1.84±2.04

	F-Ratios (1,12 df)	
	Percent germination	Germination value
Imbibed vs. dry	[1]17.20	[1]14.89
Light vs. dark	[2]4.30	[2]3.60
Interaction	.05	.61

[1] Significantly different at the 1 percent level.
[2] Significantly different at the 10 percent level.

PROCEDURE

This experiment tested the effect of red and far-red radiation on ponderosa pine seed germination. Seeds were divided into three groups (each with 32 petri dishes with 25 seeds on a moist sponge per dish) and received one of the following stratification treatments: (1) stratified at 3°±1°C for 21 days, (2) stratified at 3°±1°C for 7 days, and (3) not stratified--imbibed water at 25°C for 24 hours. Then, one subgroup consisting of four petri dishes from each stratification treatment received one of the following light treatments:

A. Dark control--no light
B. Light control--continuous light
C. 5 min red light
D. 15 min red light
E. 60 min red light
F. 60 min red and 5 min far-red light
G. 60 min red and 15 min far-red light
H. 60 min red and 60 min far-red light

After the light exposures, all replicate petri dishes except for the light controls were wrapped in foil and placed into the germination chamber. Germination was checked at weekly intervals for 3 weeks.

Each stratification group was analyzed as a separate part of the experiment using the one-way analysis of variance and a modified Scheffé's test. Comparisons of germination between similar light treatments in different stratification groups were not attempted.

RESULTS

A number of comparisons were made to determine the effect of light and stratification on germination. Increased time of stratification caused an increase in germination: 0 days of stratification, 57.4 percent germination; stratification for 7 days, 65.0 percent germination; and 21 days of stratification, 79.4 percent germination. This situation is known to be true for a variety of species of seeds.

Table 2 shows percentage germination after 21 days within each stratification treatment. Variances were again homogeneous.

Comparisons were made as follows: light control vs. dark control; dark control vs. 5-red, 15-red, and 60-red; 60-red vs. 60-red--5-far-red, 60-red--15-far-red, 60-red--60-far-red, 15-red, and 5-red; and 60-red--5-far-red vs. 60-red--15-far-red and 60-red--60-far-red.

For all stratification periods, the light and dark controls were not significantly different after 21 days of germination. It should be noted that after 7 days of germination, the light controls had a much greater number of germinated seeds than the dark controls, but this difference diminished with time.

For 0 days of stratification, 60 min of red light increased germination over the dark controls, whereas 5 and 15 min did not. All treatments with red light only were statistically the same. Fifteen and 60 min of far-red light inhibited germination below the 60 min of red treatment, but 5 min of far-red did not. Also, 15 and 60 min of far-red light inhibited germination below that of 5 min of far-red.

Table 2.--*The effect of red and far-red light, and stratification on germination of ponderosa pine seeds. (Treatments not underscored with the same dotted line are significantly different at the 10 percent level or lower.)*

Days stratified	Treatment and percentage germination							
0	60R-5FR (75)	60R (65)	5R (60)	15R (59)	Light (55)	60R-60FR (51)	Dark (50)	60R-15FR (44)
7	60R (76)	15R (75)	5R (68)	60R-60FR (66)	60R-5FR (60)	60R-15FR (60)	Light (60)	Dark (59)
21	60R (81)	60R-5FR (81)	5R (80)	60R-15FR (79)	60R-60FR (78)	Light (78)	15R (77)	Dark (76)

For 7 days of stratification 15 and 60 min of red light increased germination significantly above the dark control, whereas 5 min of red did not. However, 60 min of red did not increase germination over 5 and 15 min of red. Both 5 and 15 min of far-red light did inhibit germination below that of the 60 min of red treatment. Sixty min of far-red did not significantly reduce germination. All treatments ending with far-red light were statistically the same.

For 21 days of stratification, no significant differences in germination occurred. Germination percentages ranged from 76 to 81 percent. This corresponds in part to the findings of Hatano and Asakawa (1964), who stated that with increased periods of stratification, germination in darkness increases, sensitivity to red light increases, and sensitivity to far-red light decreases.

EXPERIMENT 3

PROCEDURE

This experiment was performed to test the effect of alternating red and far-red light on seed germination. Four light treatments plus a dark control were used. Twenty-five seeds were placed on water-soaked sponges in petri dishes. With four dishes for each treatment, the 20 dishes were placed into a dark chamber set at 25°C, allowing the seeds to imbibe for 24 hours. After this imbibition period, the seeds were given their respective light exposures. Group A, the dark control, received no light at all. Group B received 10 min of red light. Group C received 10 min of red followed by 10 min of far-red. Group D received 10 min of red, 10 min of far-red, and 10 min of red. Group E received 10 min of red, 10 min of far-red, 10 min of red, and finally, 10 min of far-red. Following the light treatments, all the petri dishes were moved to the germination chamber. Germination was observed intermittently for 24 days. Germination percentages and germination values were computed, and means were compared by a one-way analysis of variance and a modified Scheffé's test.

RESULTS

Percentage of germination and germination values of seeds exposed to the five different light treatments were as follows:

Treatment	*Percent germination ±S.D.*	*Germination values±S.D.*
A--Dark control	20.0±6.5	0.90±0.47
B--10-R	19.0±3.8	1.18±0.63
C--10-R, 10-FR	18.0±5.2	.95±0.45
D--10-R, 10-FR 10-R	39.0±8.4	4.17±1.20
E--10-R, 10-FR, 10-R, 10-FR	23.0±8.4	1.61±1.30

The percent germination and germination value of treatment D, which ended with 10 min of red light, were significantly greater than the other four treatments at the 1 percent level. The other four were statistically the same.

SUMMARY AND DISCUSSION

The results of experiment 1 revealed that germination is improved greatly with increasing seed moisture content. Light increased germination slightly but not highly significantly. Evenari (1956) stated that at the thermal optimum of germination, photosensitivity is at a minimum. Therefore, the further from this optimum temperature, the more pronounced will be the effect of light on photoblastic seeds. USDA Forest Service (1974) reported that the optimum temperature for ponderosa pine seed germination is between 75° and 86°F. Germination temperatures in these experiments ranged from 77° to 81°F, which was certainly in the optimum range. This may account for the lack of significant increase in germination with light.

The results of experiment 2 indicated that the phytochrome system may be working in ponderosa pine seeds. In most cases, 60 min of red light increased germination over that of the dark controls. Also, various amounts of far-red following a red light treatment often decreased germination below that of red light only. These results held for 0 and 7 days of stratification but not for 21 days. In all cases, the light controls did not have a higher number of germinants than the dark controls. This may have been the result of the type of light source used. A 300-watt incandescent light bulb was placed 75 cm from the seeds in the light control treatment. Withrow and Withrow (1956) reported that an incandescent light bulb puts out more energy as the wavelength increases, indicating that there is more far-red energy than red energy from this type of light source. Also, the effects of red and far-red light may have been enhanced even more had this experiment been conducted at temperatures other than the germination optimum.

Stratification time was found to be an important factor. As the cool, moist storage time increased so did germination. Therefore, just as Toole and others (1961) and McLemore and Hansborough (1970) reported, increasing stratification time breaks seed dormancy, as light apparently does.

Experiment 3 showed that the potential for the photoreversible reaction exists in ponderosa pine seeds. Two treatments of red light separated by one treatment of far-red light, increased germination significantly over the other treatments. Apparently one treatment of red light was not of sufficient intensity to cause any reaction within the seeds, as was one treatment of far-red light.

A few authors have reported the results of light quantity and quality measurements in the shade of various tree species. Atzet and Wareing (1970) reported that under certain conifer canopies the energy percentage of far-red light is increased significantly compared to direct sunlight. Other wavelength energies either decrease or do not change. Vezina and Boulter (1966) revealed that under a *Pinus resinosa* canopy, the amount of red light energy is only 14 percent compared to 23 percent in direct sunlight. The amount of far-red light increased from 18 percent in direct sunlight to 24 percent under the canopy. In both *Pinus resinosa* and *Pinus strobus* stands, a minimum energy level was found in the 670-680 nm range and a very high maximum was found in the 740-750 nm range (Federer and Tanner 1966). Therefore, we might assume that increased amount of far-red light over red light occurs under many conifer canopies.

Light conditions under forest canopies do not appear to be favorable for the breakage of seed dormancy. Cool, moist conditions can, however, prepare seeds for germination regardless of light. But, under dense canopies, snow may not accumulate and often melts early in the spring. This situation may not allow seeds the cool, moist stratification which would occur under a deep layer of snow. Rather, it subjects them to varying moisture and temperature situations which may not be proper for dormancy breakage. Therefore, under these temperature, moisture, and light conditions, many seeds of the Northern Rocky Mountain variety may not germinate. This could be an adaptation to reduce intraspecific competition for ponderosa pine, which in this region occurs in areas of low rainfall.

It must be emphasized that these results can only be applied to western Montana ponderosa pine and perhaps only the specific race from which the seeds were taken. Great differences in germination responses of ponderosa pine seeds from varying geographic areas have been found (Callahan 1962). Genetically fixed temperature responses and perhaps light and moisture responses are certainly not the same for all trees or all populations of a species.

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ROSE HIPS--A POSSIBLE HIGH-ENERGY FOOD FOR WINTERING MULE DEER?

Bruce L. Welch and Dean Andrus[1]

ABSTRACT

Mule deer wintering in northern Utah consumed hips from Woods and sweetbrier roses in Cache Valley. Except for about 1 cm of the hip's petiole, little of the woody portion was eaten. Rose hips appear to be a good source of digestible energy because the content of nitrogen-free extract is high (60.3 percent) and lignin (9.7 percent) and crude fiber (24.0 percent) content are low. Therefore, digestible energy level of browse on certain mule deer winter ranges could be raised by planting superior hip-yielding roses.

KEYWORDS: browse plants, nutrition, mule deer, winter range, rose hips

During the winter months, mule deer in Cache County, Utah, are driven by deep snows from high mountain ranges onto the foothills. There, they are forced to feed on rangelands that were grazed in the summer by livestock. With the grass gone, only woody shrubs are available. Short (1966) reports that the lack of sufficient levels of digestible energy is the most common nutritional deficiency of wintering deer. Smith and others (1975), Cook (1972), Nagy and Wallmo (1971), Hall (1970), and Dietz (1965) agree that shrubs are poor sources of digestible energy. This is due to the high cellulose and lignin content of shrubs.

Conservation of grasses on areas that are free of snow most of the winter, culture of high energy-yielding woody species, or both (Nagy and Wallmo 1971), may raise the

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digestible energy levels of mule deer winter ranges. Dietz (1965) suggests that woody species that retain their leaves, fruits, or both, throughout the winter are higher in nutritive value than those that lose such parts. Wild rose is a woody species that retains its fruit throughout the winter. Therefore, we undertook this study to determine (1) if mule deer consume rose hips, and (2) the digestible energy level of rose hips through chemical analyses. Because lignin is indigestible and deer can digest only limited amounts of crude fiber (Morrison 1961; Hall 1970; Nagy and Wallmo 1971; and Short 1963, 1966), a low lignin (12 percent or less) and crude fiber (25 percent or less) content, with a high level of nitrogen-free extract (55 percent or more), would be evidence that rose hips are high in digestible energy. Nitrogen-free extract contains the carbohydrates, such as sugars, starch, pectic substances, and others that supply digestible energy to the consuming animals (Morrison 1961). Unfortunately, indigestible lignin appears in this fraction.

STUDY SITES

Two study sites were selected. Site A was chosen to study rose hip consumption by wintering mule deer. The previous winter (1973-74), we found signs that led us to believe mule deer had eaten rose hips in this area. Although we felt strongly that deer had eaten the hips, we could not rule out the possibility that small wildlife, such as birds, could have eaten the hips before the arrival of deer. Therefore, site B was chosen to study rose hip consumption by small wildlife.

Site A

Site A is 4.0 km south and 0.8 km east of Richmond, Utah, on a game winter range. The site, about 4 ha of rangeland, is almost completely surrounded by agricultural lands. Three major shrub communities occur on the site, big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), and Woods rose (*Rosa woodsii ultramontana*). Using the field technique of Stevens and McArthur (1974), we determined that the big sagebrush was subspecies *vaseyana*. These shrubs generally grow in distinct communities with limited intermingling. Other woody species scattered throughout the site are black chokecherry (*Prunus virginiana melanocarpa*); bigtooth maple (*Acer grandidentatum*); boxelder (*Acer negundo*); river hawthorn (*Crataegus rivularis*); and sweetbrier rose (*Rosa eglanteria*).

Prior to plot establishment the summer of 1974, the site was grazed by the landowner's livestock from July to October. Woods rose was the only woody species grazed. Fortunately, in some places, this species had not been grazed, so we were able to establish grazed and ungrazed plots.

Site B

Site B is 3.2 km north and 1.6 km east of Richmond, Utah. This 0.2-ha site is on the flood plain (creek bottom) of High Creek. Major woody species within the site are black cottonwood (*Populus trichocarpa*), Woods rose, peachleaf willow (*Salix amygdaloides*), and boxelder. Of these, only Woods rose makes up a distinct community; the others are scattered throughout the site.

METHODS

Site A

On Site A two types of plots were established in October 1974: (1) Two 2 by 0.5 m rectangular plots, and (2) a trail plot through a stand of Woods rose (0.6 m wide).

One of the rectangular plots had been grazed by livestock in the summer. The other had not. On the grazed plot 13 Woods rose without hips and seven with hips were selected. The hipless rose plant would be used to determine whether or not mule deer

Figure 1.--Arrow points to black mark placed 2.54 cm from tip to rose hips. This mark was used to determine amount of rose stem eaten by mule deer.

browse hipless rose. For the ungrazed plot, 13 hipped and one hipless Woods rose were selected. All selected plants were tagged and the following data collected: number of hips, distance from stem tip or hip to nearest prickle, and number of prickles along the basal 2.54 cm. A waterproof black mark was placed 2.54 cm from hip or stem tips (fig. 1). This mark would be used to determine how much of the woody stem is browsed by deer.

The trail plot ran through a patch of heavily grazed Woods rose and alongside a clump of seven tall (1.5 to 1.8 m) plants bearing a large crop of hips. Two plants were selected and data collected as described. Thirteen hipless and eight hipped plants were selected at random along the trail.

Rose hips on a sweetbrier rose plant were counted as a basis for estimating subsequent hip consumption, if any, by deer.

In summary, we selected 30 Woods rose plants having rose hips and 27 hipless for studying deer use of rose plants; and one sweetbrier rose plant with hips.

All rose plants having hips were checked for loss or consumption of hips once a week starting December 6, 1974, and ending February 18, 1975. Hips on the ground or in the snow were counted and removed after each inspection.

Site B

An ungrazed 2 by 0.5 m plot of Woods rose was established. Because of the plot's accessibility, it was visited twice a week from December 6, 1974, to February 18, 1975. All signs of animal activity in or around the plot were recorded.

On January 10, 1975, the hips from nine Woods rose plants from the plot were harvested. Hips from the nine plants were pooled together and stored in a plastic bag (-5° C) for chemical analysis. The usual chemical means (Association of Official Agricultural Chemists 1965) were used to determine ash, kjeldahl nitrogen, calcium, phosphorus, crude fiber, crude fat, and nitrogen-free extract. Acid-detergent fiber and lignin determinations were made by following the technique of Van Soest (1963). Lignin, crude fiber, and nitrogen-free extract contents were needed to judge the potential digestible energy level of rose hips; the remaining chemical constituents were included so that comparisons with other woody species could be made.

RESULTS

Deer were first sighted January 1, 1975, by a farmer on Site A. Two days later we inspected the plants. Deer had already eaten 92 percent of the rose hips on selected plants (table 1). All sweetbrier roses had deer tracks leading to and around them. Freshly cut stem tips showed that deer had eaten the hips from these bushes.

Vasey big sagebrush showed signs of being heavily browsed by deer. It was clear that deer preferred rose hips and sagebrush as browse. Black chokecherry and antelope bitterbrush were not heavily browsed for another month.

Because of the deep snow and the proximity of a busy paved road to the Site B plot, we had not expected deer to move into the area; so results of the February 18, 1975, inspection came as a surprise. Mule deer had eaten over 90 percent of the rose hips. We found no evidence that other animals were eating rose hips previous to this inspection.

A careful inspection (March 28, 1975) of hipless Woods rose plants on Site A indicated deer had consumed less than 1 percent of the woody portions on rose plants without hips. The deer were eating the hips and about 1 cm of the hip's petiole.

Rose hips were lower in crude fiber (24.0 percent), protein (6.1 percent), lignin (9.7 percent), phosphorus (0.13 percent), and ash (3.6 percent) than big sagebrush and alfalfa (table 2). Hips were higher in nitrogen-free extract (60.3 percent) than big sagebrush (43.7 percent) and alfalfa (40.6 percent).

Woods rose varied greatly in prickliness. The average distance from hip or stem tip to first prickle was 17.3 cm with a standard deviation of ± 14.7 cm for 57 rose plants. Prickliness did not affect utilization or selectivity of hips by mule deer. Even the numerous large prickles of sweetbrier rose did not keep deer from eating hips.

The loss of Woods rose hips to summer livestock grazing was striking. In the grazed plots, the number of hips per plant was 2.5; on the ungrazed plots, the per plant yield was 15.

Table 1.--*Number of hips on Woods rose and sweetbrier rose plant before and after browsing by deer, Site A.*

	No. of hips on plants 12/6/74	No. of hips on plants 1/3/75	No. of hips in snow 1/3/75	Consumed by deer
				Percent
Woods rose (30 plants)	413	25	8	92
Sweetbrier Rose (1 plant)	357	13	12	92
Total	770	38	20	92

Table 2.--*Comparisons of the chemical composition of Woods rose hips (data from this study), big sagebrush,*[1] *and alfalfa*[1]

	Protein	Cell.	Lignin	Crude Fiber	Crude Fat	ADF[2]	Ash	Cal.	Phos.	NFE[3]	TDN[4]
						Percent					
Rose hips	6.1	--	9.7	24.0	6.0	23.3	3.6	0.75	0.13	60.3	--
Big sagebrush	9.4	21	16.0	[5]24.8	10.1	--	6.1	.67	.18	[5]43.7	51
Alfalfa	17.1	30	11.3	30.1	2.0	[6]29.8	8.5	1.35	.22	[5]40.6	57

[1]National Academy of Sciences (1964).
[2]ADF = Acid-detergent fiber
[3]NFE = Nitrogen-free extract
[4]TDN = Total digestible nutrients
[5]Morrison, F. B. (1961). Percentages converted to dry matter basis.
[6]Schwartz, C. C., and J. G. Nagy (1974).

CONCLUSIONS

Mule deer prefer rose hips over black chokecherry and antelope bitterbrush but not Vasey big sagebrush. Rose hips may be a high source of digestible energy. We base this conclusion on low lignin and crude fiber content accompanied by a high content of nitrogen-free extract. Therefore, digestible energy levels in the diet of deer might be increased by planting rose stock that produces heavy crops of hips (Blauer and others 1975).

Summer grazing of Woods rose by livestock greatly reduced the number of hips available to wintering deer. However, livestock did not graze sweetbrier rose--possibly due to the presence of large, heavy prickles. On winter ranges subjected to livestock grazing, sweetbrier rose may furnish more deer feed than Woods rose.

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CALLUS PROLIFERATION AND DIFFERENTIATION OF *RIBES* SPP. *IN VITRO*

A. E. Harvey and J. L. Grasham[1]

ABSTRACT

Media satisfactory for the induction of callus proliferation from primary explants of Ribes nigrum, R. petiolare, *and* R. viscosissimum *contained (g/l): calcium nitrate 0.5, magnesium sulfate 0.14, potassium phosphate (monobasic) 0.14, ammonium sulfate 0.025, ferric sulfate 0.014, manganese sulfate 0.0035, sucrose 30.0, Noble agar 10.0, kinetin 0.001, plus IAA 0.1, NAA 0.01, or 2,4-D 0.00015 (pH 6.0). This medium maintained callus proliferation for periods up to 6 months with one subculture. Additions of myo-inositol 0.0002, ascorbic acid 0.0002, Biotin 0.00001, thiamine 0.0001, and pyrodoxine 0.0001 extended explant longevity but were not required. Primary explants and first subcultures of* R. nigrum *and* R. petiolare, *on the complete medium plus IAA (g/l), 0.0001, 0.001 and 0.01, formed roots, roots and shoots, and shoots, respectively. Only roots were formed in the absence of kinetin.*

KEYWORDS: *Ribes*, tissue culture, callus proliferation, differentiation, root induction, shoot induction

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Studies of the host-parasite interactions of the mononucleate stage of *Cronartium ribicola* J.C. Fisch. ex Rabenh. in tissue cultures of *Pinus monticola* Dougl. (Harvey and Grasham 1969; Harvey and Woo 1971; Robb and others 1974a, 1974b) have provided basic knowledge concerning the histopathological and nutritional interactions of these two organisms. Tissue cultures of the *Ribes* host would further studies of the binucleate stage. Comparison of the two should provide a better understanding of the similarities or differences between the nuclear stages of this rust, and perhaps a clearer understanding of each. This paper describes procedures and media for inducing callus proliferation and differentiation of *Ribes nigrum* L., *R. petiolare* Dougl., and *R. viscosissimum* Pursh. Insofar as possible, the basic approach paralleled that previously described for the pine host of this important parasite (Harvey 1967; Grasham and Harvey 1970).

MATERIALS AND METHODS

Primary explants were prepared from either 2-cm-long stem sections or 0.5-cm-long petiole sections taken from current year's shoots of 3- to 5-year-old, greenhouse-grown, potted plants or wildings of the three species under study. Sections of either tissue from all species were rinsed in rapidly running water for 2 h and sterilized for 10 min (with constant agitation) in 0.525 percent sodium hypochlorite. All tissues were subsequently rinsed in three changes of sterile, distilled water. Petiole sections, after excising 1 mm pieces from both ends to remove injured tissues, were planted by embedding the acropetal end 0.25 cm into an experimental medium. Stem sections were taken from the internodes between the fifth and eighth leaf below the actively growing meristem. In this area the cortex layer was well developed but lenticular tissues were poorly developed and were not visible on the external surface. Surface-sterilized sections were further prepared by aseptically removing the epidermis, cutting into 0.5-cm lengths, and planting as above, or by subsequently removing the cortex layer from the pith and dividing the resultant sheets of stem cortex into 1-cm squares. These were placed, internal surface down, on an experimental medium.

Media were developed by adding an auxin and kinetin (6-furfurylaminopurine) in specified ratios to vitamins, amino acids, casein hydrolysate, peptone and yeast extract, singly or in combinations, at various concentrations, to the basal medium previously developed for *P. monticola* (Harvey 1967; Harvey and Grasham 1969; Grasham and Harvey 1970). This basal medium contained (g/l); calcium nitrate 0.5, magnesium sulfate 0.14, potassium phosphate (monobasic) 0.14, ammonium sulfate 0.025, ferric sulfate 0.014, manganese sulfate 0.0035, sucrose 30.0, and Noble agar 10.0 (table 1). All organic additives were filter sterilized prior to incorporation into the autoclaved (15 lb for 20 min) basal medium (50° C).

Callus cultures were incubated under a 24-h cyclic regimen: 16 h at 21° C, 400 footcandles, and 8 h at 5° C, no light.

All media were prepared with double-distilled water (pH 6.5); the second distillation was in an all-pyrex-and-Teflon-glass still.

RESULTS

Excellent callus proliferation was achieved with all three types of primary explants from all three species on the basal medium described amended with (g/l) indoleacetic acid (IAA) 0.1, napthaleneacetic acid (NAA) 0.01, or 2,4-dichlorophenoxyacetic acid (2,4-D) 0.00015, in combination with kinetin 0.001. IAA, NAA, and 2,4-D at concentrations greater than 0.1, 0.01, and 0.0005, respectively, were toxic. IAA and NAA were inferior to 2,4-D. See example of *R. nigrum* in table 1. The former caused etiolation and necrosis of all three species after 45 days. In addition, subculturing of callus tissues grown on these two auxins was difficult.

Table 1.--*Relative efficiency of various auxin/kinetin combinations, added to the basal medium, in inducing callus growth, root and shoot formation 60 days after explanting 1-cm squares of stem cortex from* R. nigrum

Acid	Auxin	Kinetin	Relative abundance[1]			
			Callus growth	Roots	Shoots	Callus necrosis
	- - - - - - *g/l*	- - - - - -				
IAA	0.0001	0.001	+	++	0	+
IAA	0.001	0.001	++	++	++	+
IAA	0.01	0.001	++	0	0	+
IAA	0.1	0.001	+++	0	0	+
NAA	0.01	0.001	+++	0	0	+
2,4-D	0.00015	0.001	+++++	0	0	0

[1] Rated from 0 to +++++ where the latter was optimum, intermediate levels based on visual comparisons.

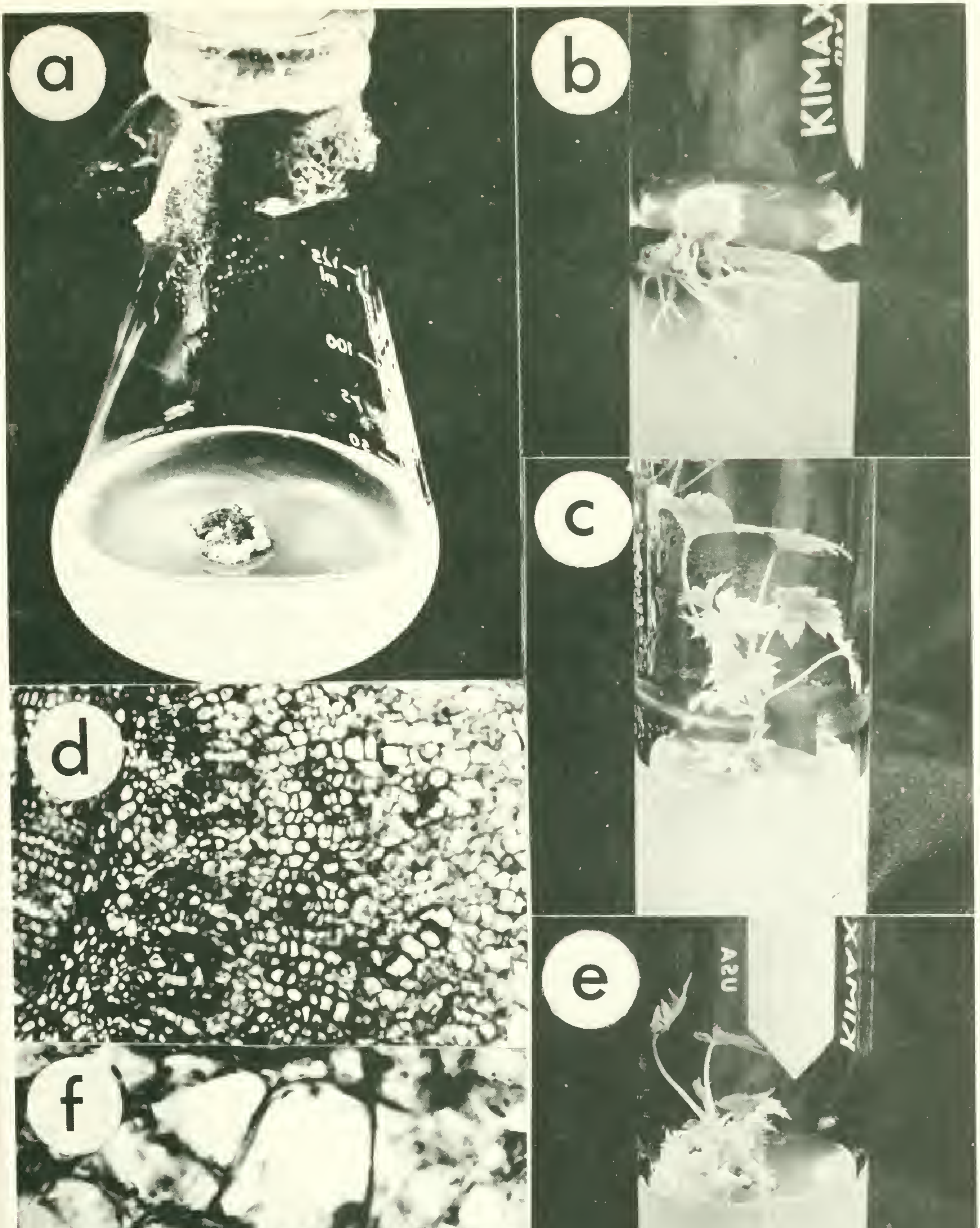
Excellent proliferation was produced by primary explants derived from the 1-cm^2 sections of stem cortex. General vigor of the three types of explants of all three species was enhanced by the addition of (g/l) myo-inositol 0.0002, ascorbic acid 0.0002, biotin 0.00001, thiamine 0.0001, and pyrodoxine 0.0001, particularly in the presence of vitamin-free casein hydrolysate 0.01, bacto-peptone 0.50, or yeast extract 0.50.

Callus growth was firm but friable; and, although chlorophyll production was evident in the first 30 days, the proliferating tissues generally became etiolated. Only tissues derived from excised stem cortex continued to proliferate for periods in excess of 90 days without subculture. This tissue acquired a zonate pattern of growth with recurring proliferation approximately every 45 days (fig. 1a). Histological examination revealed recurring meristematic layers (fig. 1d). All callus tissues consisted of large, thin-walled cells organized into loosely cemented tissue masses (fig. 1f).

Subcultures of 15-mm^3 cubes of healthy callus (without primary tissue) from any of the three explant types from *R. nigrum* and *R. petiolare* could be maintained, by continuous subculture of vigorous material, for periods up to 6 months (five to eight generations). Frequently, extensive necrosis prevented additional transfers after 90 days. Explants from *R. viscosissimum*, particularly excised stem cortex, proliferated rapidly for the first 60 days, but degenerated if not subcultured at about 21-day intervals. Petiole-derived callus from all three species was slow growing and became necrotic after 90 days without subculture.

Differentiation of roots and shoots in primary explants or the first subculture of *R. nigrum* and *R. petiolare* was easily obtained by varying IAA/kinetin ratios (table 1). However, after the first transfer, callus tissues did not differentiate. NAA or 2,4-D maintained cultures did not differentiate. Figures 1b, e, and c are typical of the differentiation patterns obtained with primary explants or first subcultures propagated on the basal medium plus (g/l) kinetin 0.001 and IAA at 0.0001, 0.001, and 0.01, respectively. These examples were obtained from stem cortex primary explants. Pith tissues had not been removed. Photographs were taken 90 days after beginning the cultures. IAA at (g/l) 0.1 supported callus proliferation but inhibited both root and shoot formation. In the absence of kinetin, differentiation rarely occurred from proliferating callus tissues. In those cases where it did occur, only roots were formed.

Figure 1.--(a) Callus development from a stem cortex explant after 120 days, without subculture, 2,4-D (g/l) 0.00015. Note the zonate growth pattern. (b) Root formation in a stem segment primary explant after 60 days, 0.0001 IAA and 0.001 kinetin. (c) Shoot formation in a stem segment primary explant after 60 days, 0.01 IAA and 0.001 kinetin. (d) Cross section through callus shown in 1a, 200X. Note recurring meristematic layers. (e) Root and shoot formation in a stem segment primary explant after 60 days, 0.001 IAA and 0.001 kinetin. (f) Cross section of the large thin-walled callus cells produced from a stem cortex explant after 30 days, 400X. Cross sections prepared in paraffin and stained with Sass' triple stain.


a
b
KIMAX
c
d
e
f

DISCUSSION

Although the mineral salts and organic compounds essential to induce callus proliferation of the three *Ribes* species are relatively few, it is apparent that one or several of the compounds used in our test media are either limiting, toxic, or both; or the media are deficient in some other essential nutrient. However, careful preparation of subcultures, to remove all necrotic tissues formed in the previous transfer, was helpful for long-term propagation. Because tissues were grown in an environment that provided periodic light, the gradual etiolation as cultures aged would appear to be related to the onset of necrosis.

One could speculate that the zonate growth pattern exhibited by *Ribes* tissue cultures, most evident in callus derived from stem cortex, may be related to an endogenous circadian cycle. Such a cycle may also interfere with continuous growth in culture if the dormancy requirements of the species have not been compensated for in the artificial environment.

The ability of *Ribes* callus to differentiate roots and shoots was severely inhibited by continuous subculture. Callus propagated beyond the first subculture rarely differentiated and, if it did, roots and not shoots were formed. Similar loss of the capability to differentiate has also been reported for *Geranium* callus (Pillai and Hildebrandt 1969).

Auxin levels required for the propagation of *Ribes* sp., a woody perennial shrub, were slightly lower than those required for many forest tree species, including both woody dicots (Jacquiot 1964; Wolter 1964; Wolter and Skoog 1966; Winton 1968) and conifers (Harvey 1967; Brown and Lawrence 1968; Harvey and Grasham 1969). This may be indicative of differences in the endogenous auxin levels correlated directly or indirectly to physical stature, apical dominance, or both.

The differentiation pattern of *Ribes* callus was directly related to IAA/kinetin ratios in the medium. This pattern was characterized by root formation at low auxin/kinetin ratios (g/l) (0.0001/0.001), both root and shoot formation at intermediate ratios (0.001/0.001), and shoot formation at high ratios (0.01/0.001), followed by complete inhibition of differentiation at high auxin concentrations (0.1). IAA became toxic beyond 0.1 g/l. This general pattern of auxin/kinetin control of differentiation was reported for aspen callus (Winton 1968), but the auxin concentrations used were somewhat higher. For herbaceous dicots, the pattern was different and frequently reversed (Pillai and Hildebrandt 1969; Skoog and Miller 1957; Torrey and Sigemura 1957; Vasil and Hildebrandt 1966a, 1966b; Wilmar and Hellendorn 1968; Halperin 1969). Thus, it is apparent that a great many endogenous factors and environmental requirements control the expression of growth-regulator-induced differentiation in culture.

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Research Note INT-223 June 1977

BASE-AGE CONVERSION AND SITE-INDEX EQUATIONS FOR ENGELMANN SPRUCE STANDS IN THE CENTRAL AND SOUTHERN ROCKY MOUNTAINS

Gary W. Clendenen, Forester

ABSTRACT

Two mathematical models are presented. The first is used to convert 100-year base-age site index to 50-year base-age site index. The second describes 50-year base-age site index as an equation suitable for use with data processing by computer. Fifty-year base-age site-index curves and a base-age conversion curve are also presented.

KEYWORDS: site index, mathematical model, Engelmann spruce, spruce-fir, central and southern Rocky Mountains

A conventional tool for estimating productivity of forest land is site index (Alexander 1974). Site-index curves for Engelmann spruce *(Picea engelmannii* Parry), developed by Alexander (1967) for the central Rocky Mountains, are accepted as the standard throughout the central and southern Rocky Mountains. Jones (1974) says Alexander's curves give reasonable estimates of Engelmann spruce site index in the Southwest as well.

However, Alexander does not give a mathematical representation of his curves. For processing data by computer, it is desirable to be able to define the site-index relationship mathematically. Alexander presents the commonly used 100-year base-age site-index curves. Many users of site index prefer to use a 50-year base age; therefore, I converted the 100-year base age to a 50-year base age before developing the model for site index.

I developed the base-age and site-index models presented here by using a combination of Matchacurve techniques (Jensen 1964; Jensen and Homeyer 1970, 1971; Jensen 1973, 1976) and linear regression techniques (Draper and Smith 1966).

The purpose of this paper is to present base-age conversion and 50-year base-age site index as mathematical equations for processing large amounts of data by using computers.

BASE-AGE CONVERSION MODEL

Expected heights of Engelmann spruce trees in the dominant stand (Alexander 1967) at the 100-year breast-height age were fitted across site index using least-squares linear regression techniques to expected height at 50 years. The estimated height at 50 years is then the 50-year base-age site index. The equation for converting 100-year base-age site index to 50-year base-age site index for Engelmann spruce is:

$$S_{50} = \frac{S_{100} - 14.19432717}{1.276403138} \quad \text{or,} \quad S_{100} = 1.276403138(S_{50}) + 14.19432717$$

where

S_{100} = site index, 100-year base age (breast height)

S_{50} = site index, 50-year base age (breast height)

R^2 = 0.9998

The relationship between 50- and 100-year base age is shown in figure 1. The maximum deviation is 0.4444 site-index value (50-year base age) and the mean deviation is 0.2096 site-index value.

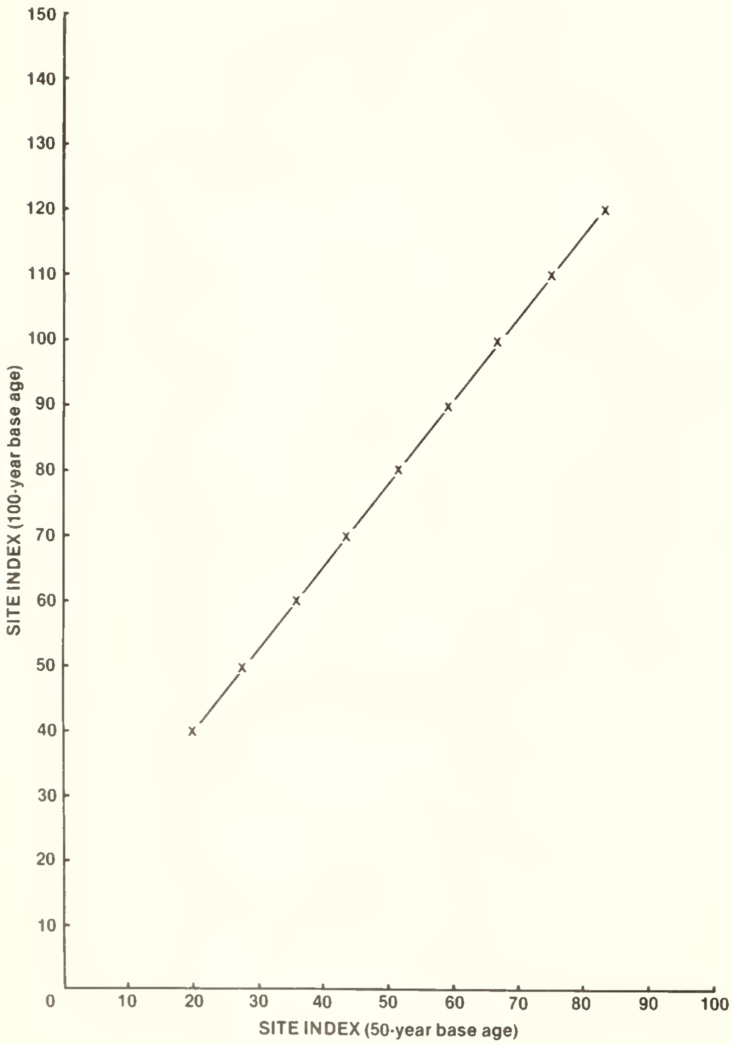

Figure 1.--Relationship of Engelmann spruce 100-year base-age site index to 50-year base-age site index for Central and Southern Rocky Mountains. Each data point is shown as an x.

SITE-INDEX MODEL

Alexander presents 100-year base-age (breast height) site-index curves for site indexes 40 through 120. Average total height and average breast-height age of the dominant stand are needed to determine site index from the curves. To build the model to change site-index base age, I used all data points from Alexander's expected height of Engelmann spruce trees in the dominant stand (Alexander 1967).

The first step in developing the site-index model was to fit 50-year base-age site index to expected height for each age class using least-squares linear regression techniques. For each age class, site index was found to be a linear function of expected height.

The second step was to use Matchacurve techniques to determine appropriate transformations of breast-height age for the y-axis intercepts and slopes of the linear function found in the first step. It was found that the best transformations of breast-height age for both the y-axis intercept and the slope changed at 50 years of age breast height; therefore, a segmented model was fitted.

The third step was to fit the y-axis intercepts and the slopes to the breast-height age transformations. A check of this preliminary model showed the model did not pass exactly through the known heights at 100 years; so a correction factor was developed. Application of the correction factor increases the variation around the function slightly.

The site index model that I developed from Alexander's curves is:

$$S = a + bH$$

where

S = site index, base age 50 years (breast height)

H = average total height of 6 or more dominants:

20 to 50 years of age breast height:

$$a = 7.321450260 - 0.087970990\ (A - 20.0)^{1.3}$$

$$b = 2.236555891 - 0.430830223\ (A - 20.0)^{0.31}$$

51 to 300 years of age breast height:

$$a = -25.40943950 + 1.477047639E\text{-}05\ (300.0 - A)^{2.6}$$

$$b = 0.712121213 + 7.457608936E\text{-}17\ (300.0 - A)^{6.5}$$

A = average breast-height age of dominants in stand

$R^2 = 0.9906$

Fifty-year base-age site-index curves for Engelmann spruce are shown in figure 2. Table 1 presents 50-year base-age site index for specific dominant stand heights and stand ages.

I checked this model by comparing predicted heights with Alexander's estimated heights. Since the largest deviation is 2 feet in estimated height and the mean deviation is 0.4789 foot, this model is considered to be adequate. The model will not function below 20 years or over 300 years.

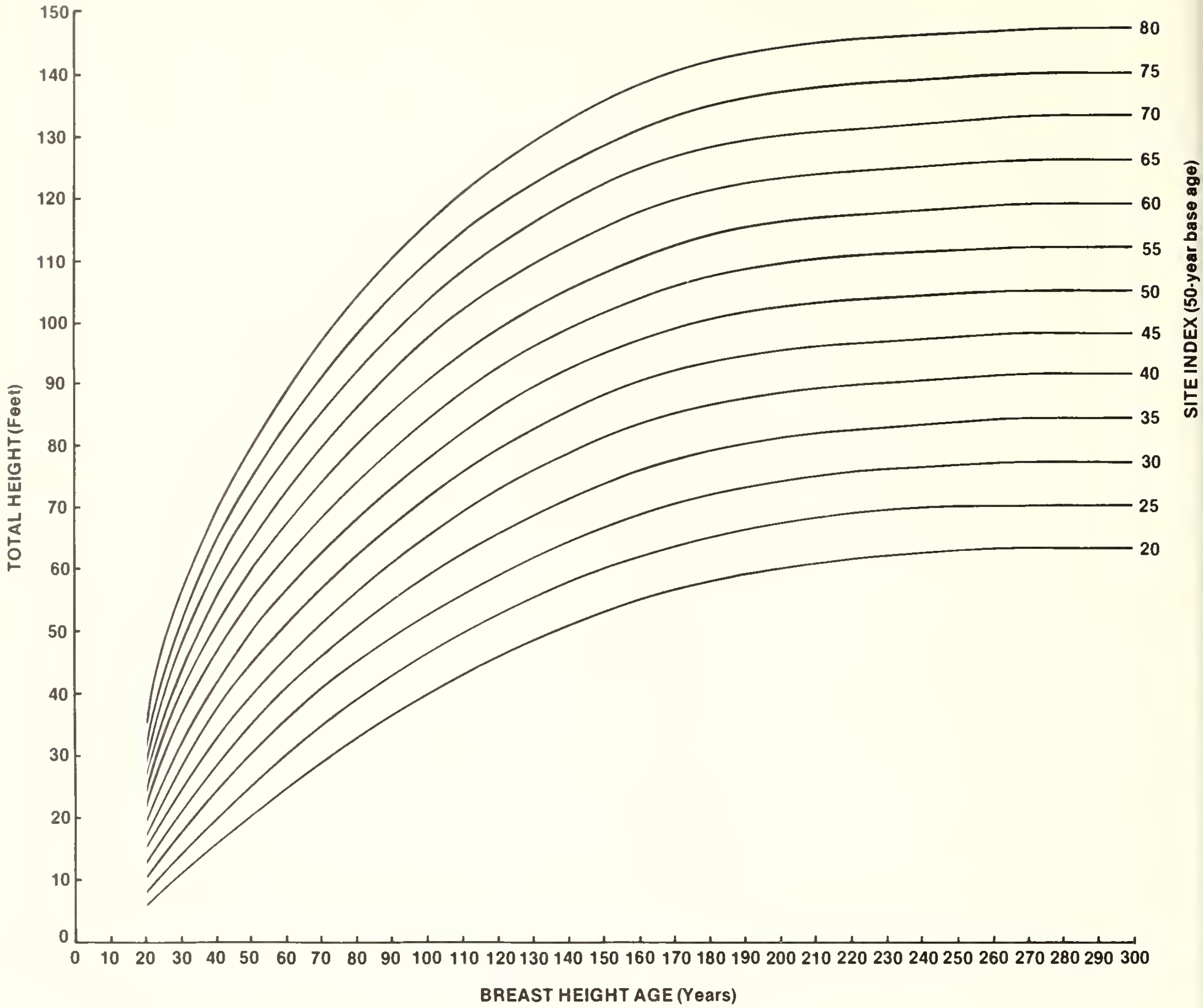

Figure 2.--Site-index curves for Engelmann spruce in the Central and Southern Rocky Mountains.

Table 1.--*Expected site index (50-year base age) for Engelmann spruce stands in the Central and Southern Rocky Mountains*

Stand age[1]	Height of dominant stand in feet: 10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
20	30	[2] 52	74	97	119	--	--	--	--	--	--	--	--	--	--
30	19	33	46	60	73	87	101	114	--	--	--	--	--	--	--
40	14	26	37	49	60	72	83	95	106	118	--	--	--	--	--
50	10	20	30	40	50	60	70	80	90	100	110	120	--	--	--
60	7	16	25	35	44	53	63	72	81	91	100	109	119	--	--
70	4	13	21	30	39	48	57	65	74	83	92	101	109	118	--
80	1	10	18	26	35	43	51	60	68	77	85	93	102	110	118
90	0	7	15	23	31	39	47	55	63	71	79	87	95	103	111
100	--	4	12	20	28	36	43	51	59	67	75	82	90	98	106
110	--	2	10	17	25	33	40	48	55	63	71	78	86	93	101
120	--	0	8	15	23	30	38	45	53	60	67	75	82	90	97
130	--	--	6	13	21	28	35	43	50	57	65	72	80	87	94
140	--	--	4	12	19	26	33	41	48	55	63	70	77	84	92
150	--	--	3	10	17	25	32	39	46	54	61	68	75	82	90
160	--	--	2	9	16	23	31	38	45	52	59	66	74	81	88
170	--	--	1	8	15	22	29	37	44	51	58	65	72	79	87
180	--	--	0	7	14	21	28	36	43	50	57	64	71	78	86
190	--	--	--	6	13	20	28	35	42	49	56	63	70	77	85
200	--	--	--	5	13	20	27	34	41	48	55	62	70	77	84
210	--	--	--	5	12	19	26	33	40	48	55	62	69	76	83
220	--	--	--	4	12	19	26	33	40	47	54	61	68	76	83
230	--	--	--	4	11	18	25	32	40	47	54	61	68	75	82
240	--	--	--	4	11	18	25	32	39	46	54	61	68	75	82
250	--	--	--	3	11	18	25	32	39	46	53	60	68	75	82
260	--	--	--	3	10	18	25	32	39	46	53	60	67	75	82
270	--	--	--	3	10	17	25	32	39	46	53	60	67	74	82
280	--	--	--	3	10	17	24	32	39	46	53	60	67	74	81
290	--	--	--	3	10	17	24	32	39	46	53	60	67	74	81
300	--	--	--	3	10	17	24	32	39	46	53	60	67	74	81

[1] Average breast-height age of dominants in stand.
[2] The blocked-in area represents the extent of Alexander's Engelmann spruce site-index curves. Values outside the blocked-in area are extrapolated from the curve form and therefore should be used with extreme caution.

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CHANGES IN RIBONUCLEASE ACTIVITY RESULTING FROM STEM INFECTIONS OF WESTERN WHITE PINE BY BLISTER RUST

A. E. Harvey[1]

ABSTRACT

Ribonuclease activities in cell-free extracts of western white pine stem tissues infected by blister rust were determined within and near active infection centers. Enzyme activity of samples taken from the infection centers, the actively sporulating margins, newly infected margins, and from bark tissues well in advance of infection showed characteristic changes in catalytic properties. These included changes in specific activity, in substrate specificity, and in heat stability.

KEYWORDS: ribonuclease, white pine, blister rust, host-parasite interaction, physiology, *Pinus monticola, Cronartium ribicola.*

The efficiency of ribonuclease extraction and assay procedures (Tang and Maretzki 1970; Udvardy and others 1969; Wyen and others 1969; Wilson 1967, 1968) and the demonstrable effect on this enzyme system by parasitism of blister rust (*Cronartium ribicola* J.C. Fisch.) in pine tissue cultures and *Ribes* leaves (Harvey and others 1974) and other rust fungi on their respective hosts (Scrubb and others 1972; Rohringer and others 1961) suggested similar changes might occur in pine stem infections. This research was undertaken to document changes in ribonuclease activity in blister-rust-infected pine seedling stems. These measurements provide a basis for comparing host-parasite interactions in a tissue culture environment (Harvey and Grasham 1969) with those of a natural system.

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MATERIALS AND METHODS

Seedlings of western white pine (*Pinus monticola* Dougl.) were derived from open pollinated seed collected in the St. Joe National Forest in northern Idaho. These were grown in nursery beds for 8 years. Both healthy and infected plants came from blocks of the same planting. Three years prior to sampling, part were inoculated according to the following procedure. Five-year-old seedlings in nursery beds were enclosed in wood framing that extended 25 cm above their growing tips. This framing was covered with a coarse wire mesh. After fogging of the enclosed seedlings with tapwater, teliospore-bearing leaves from western black currant (*Ribes petiolare* L.), collected in the St. Joe National Forest in September, were placed on the wire mesh spore side down. The leaves were, in turn, covered with several layers of burlap cloth kept moist throughout a 72-hour inoculation period.

Samples for ribonuclease (RNase) extraction were obtained by excising cortex tissues from the following locations at or above the center of single infections from 20 stems and tissues of the same age from 10 healthy stems (collected in May 1972). Infected tissues were obtained from (1) the innermost to the outermost (nonnecrotic) edges of the aeciospore-bearing region (insofar as possible, spores were gently removed prior to extraction with a soft plastic brush), (2) the innermost to the outermost limits of the nonsporulating region (determined by the yellow discoloration), (3) 7-mm strips of tissues whose inner edge was 3 mm and outer edge was 10 mm beyond the yellow margin, and (4) 3-cm strips of tissues whose inner edge was 2 cm and outer edge was 5 cm beyond the yellow margin of the rust infections. All samples were divided into 5-g lots and frozen immediately after collection.

All possible care was exercised to prevent contamination of the RNase between samples or with that from any external source. Handling of tissues in preparation for and of samples during extraction was accomplished with scrupulously cleaned instruments and vessels while wearing disposable plastic or latex gloves.

For extraction, 5 g (fresh weight) of excised pine-stem cortex tissues were suspended in 25 ml of ice-cold, 5-mm potassium phosphate extraction buffer, pH 6.7, containing 2 g polyvinylpyrolidone (PVP Sigma Chemical Co.). This mixture was homogenized with an Omni Mixer (Sorvall, Inc.) set at high speed for six 30-second periods, with 30 seconds between runs. The stainless steel homogenizer vessel was immersed in an ice-water bath throughout. The homogenate was centrifuged (5° C) for 30 minutes (10,000 rpm) in a refrigerated centrifuge (Sorvall RC2-B). The supernatent was dialyzed immediately (5° C) according to the following schedule: 2 hours in 400 ml, 4 hours in 1,000 ml, and 24 hours in 2,000 ml of extraction buffer. The enzyme concentrate was used directly for protein estimations, RNase determinations, and measurement of potential hydrolytic activity by Deoxyribonuclease (DNase), phosphodiesterase, alkaline, and acid phosphatase (Scrubb and others 1972).

All assay procedures were as described previously (Harvey and others 1974; Scrubb and others 1972). The pH optimum for the reaction mixture was 4.5.

One unit of RNase is herein defined as the quantity of enzyme catalyzing an increase in A_{260nm} of 1.0 under the standard conditions of assay. Specific activity of RNase is described in units/mg protein. The specific activities of other hydrolases are expressed as ΔOD at the appropriate wavelength/mg protein.

RESULTS AND DISCUSSION

Initially, estimating protein in pine stem tissues, particularly infected tissues, proved difficult. This problem was related to the presence of dialyzable extractives, probably low molecular weight phenolics, that caused excessive color in extracts at the $280/260_{nm}$ range. Extensive dialysis, as noted in the methods, resolved the problem.

Although the conditions prevailing during extraction and in the RNase reaction vessels were generally unfavorable to hydrolytic contributions from DNase, phosphodiesterase, alkaline and acid phosphatase, their potential activity was measured. Table 1 summarizes typical values for these enzymes when tissue extracts were assayed under optimum conditions for each. Even under these conditions the rates of hydrolytic activity in infected tissue extracts were lower than in healthy tissue extracts. This is a clear indication that these enzymes did not contribute substantially to ribonucleic acid (RNA) hydrolysis.

In a test to determine the effect of mechanical injury, healthy stem cortex tissues were sectioned into 2 mm squares, then incubated for 12 hours prior to extraction. No changes in RNase or heat stability resulted. The differences in the specific activities and heat sensitivities of RNase extracts from healthy and from locations in and near infections of pine-seedling stems showed a definite pattern of changes (fig. 1). Changes in the substrate specificity of RNase extracts showed a pattern of change resulting in similar specificities in all tissues under the influence of the parasite (table 2).

Table 1.--*Changes in the activities of enzymes (other than ribonuclease), capable of hydrolyzing the phosphodiester bond, from healthy and blister-rust infected pine-stem cortex*

Tissue	Hydrolytic enzyme ΔOD at appropriate wavelength per mg protein: DNase	Acid phosphatase	Alkaline phosphatase	Phosphodiesterase
Healthy pine stem	10.0	15.0	16.2	0.0
Infected pine stem	5.5	12.0	9.5	0.0

Table 2.--*Hydrolysis of ^{3}H-labeled polynucleotides by RNase extracts from blister rust-infected and healthy pine-stem cortex tissues. Infected samples taken from (1) between 3 and 30 mm beyond the discolored zones above infected areas, and (2) from within the discolored region excluding the sporulating area*

Tissue	Hydrolysis dpm/mg protein: Poly A	Poly C	Poly U	Total dpm	Preference
Healthy	19,035	35,142	0	54,177	C>A>U
3-30 mm	21,833	15,916	0	37,749	A>C>U
Infected	39,924	3,166	0	43,090	A>C>U

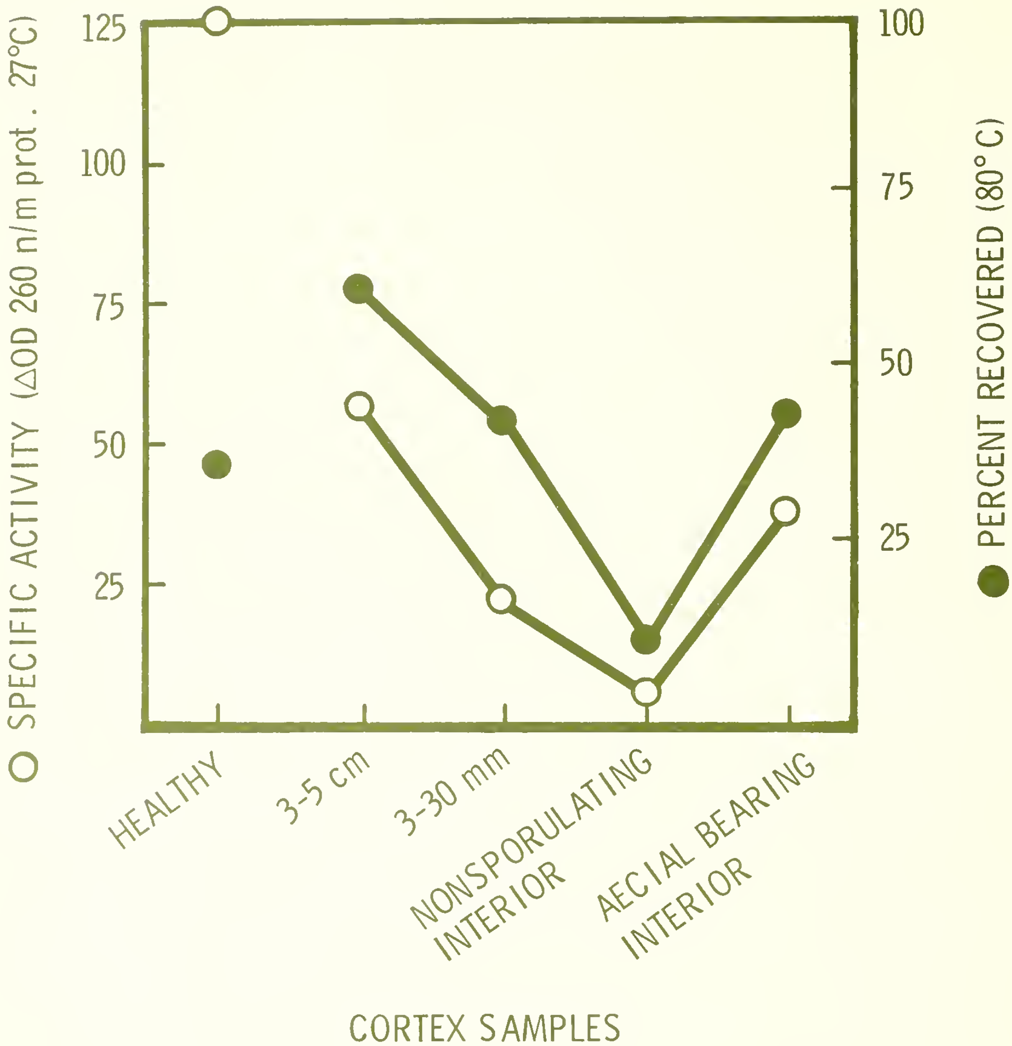

Figure 1.--Soluble RNase specific activity and respective temperature stabilities from healthy and infected pine-stem cortex. Specific activity expressed in ΔOD 260 nm/mg protein at 27° C. Temperature sensitivity determined by heating the enzyme solution to 80° C for 10 minutes, then cooling in an ice bath prior to adding the substrate.

CONCLUSIONS

The data show a strong similarity to the *in vitro* and *in vivo* systems used previously. They are consistent with the following generalizations regarding white pine-blister rust interactions:

1. All infected tissues (pine stems, *Ribes* leaves, and pine-tissue cultures) contain a unique RNase present in neither healthy nor mechanically injured tissues (this paper; Harvey and others 1974).

2. Many changes are apparent in tissues adjacent to, but not yet penetrated by this parasite (this paper; Harvey and others 1974; Robb and others 1974).

The results support the hypothesis that axenic culture systems provide a valid tool with which to dissect a host-parasite combination in order to study both the components and their interactions.

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August 1977

DIFFERENTIAL SUSCEPTIBILITY OF 19 WHITE PINE SPECIES TO WOOLLY APHID (*PINEUS COLORADENSIS*)

R. J. Hoff and G. I. McDonald[1]

ABSTRACT

Several species of white pine appeared to be completely resistant to woolly aphid; others were highly susceptible. The level of infestation tended to be highest for species in subsection Strobi, for species from the North American Continent, and for species that are most susceptible to white pine blister rust.

KEYWORDS: White pine, woolly aphid, *Pineus coloradensis*, resistance to insects

Woolly aphids are common pests on conifers. Some like the balsam woolly aphid (*Adelges piceae*) on the true firs are very destructive (U.S. Department of Agriculture 1972; Page 1975). Several other species of the genus *Adelges* and the closely related genus *Pineus* can also at times cause severe damage and even mortality (U.S. Department of Agriculture 1972; Canadian Forestry Service 1965-1974).

Two common species of woolly aphids on white pines native to North America are *Pineus pinifoliae* and *P. coloradensis*. These species are usually minor pests in natural stands. However, in greenhouses and lathhouses these woolly aphids are a constant threat to the health and vigor of white pine seedlings. Normally when a few aphids are seen, measures are taken to quickly stop the infestation with an appropriate insecticide. Nevertheless, an epidemic of the woolly aphid, *P. coloradensis* (identified by L. M. Russell, U.S. National Museum), occurred in an experiment designed to evaluate the resistance of 19 species of white pine to blister rust. Differential susceptibility of some of these species to the infestation appeared to exist. While design circumstances discouraged statistical evaluation of susceptibility, the results were so strongly displayed as to suggest hypotheses of potential research interest to geneticists and entomologists.

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[1]The authors are, respectively, principal plant geneticist and principal plant pathologist, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

MATERIALS AND METHODS

Seedlings of 19 species (table 1) of white pine were grown in 2- by 2-inch pots. Fifty seedlings of each species were grown together as a plot. There were one to eight plots per block, and there were four blocks. Positions of the plots were randomized within each block (fig. 1).

The seedlings were maintained in a dormant condition in a greenhouse from October to May and in a lathhouse during the growing season. The seedlings became infested with the woolly aphid during July of the third growing season. At that time, the level of infestation of each plot was numerically rated.

Table 1.--*Observed level of infestation of white pines infested with woolly aphid and the degree of resistance to white pine blister rust*

Subsection and species	Continent	Blocks 1	2	3	4	Number of seedlings per species
		- - *Levels of infestation per plot*[1] - -				
		SUBSECTION CEMBRAE				
Pinus albicaulis (Whitebark pine)	N. Am.	1,1,1	0,1,1	1,1,1	1,1,1	217
P. cembra (Swiss stone pine)	Eur.	0,0,0	0,0,0	0,0,1	0,0,1	302
P. koraiensis (Korean pine)	Asia	0,0,1	0,0,0	0,0,1	0,0,1	441
P. pumila (Japanese stone pine)	Asia	2,0,0	0,0,0	0	0,0	15
P. sibirica (Siberian stone pine)	Asia	0,0,0	0,0,0	0,0,0	0 0,0	443
		SUBSECTION STROBI				
P. armandii (Armand pine)	Asia	0	0	0	0	200
P. ayacahuite (Mexican white pine)	N. Am.	1,1	1,1	1,1	2,2	399
P. chiapensis (Southern white pine)	N. Am.	3,3	3	3	3	129
P. flexilis (Limber pine)	N. Am.	1,0	0,0	1,0	1,0	369
P. lambertiana (Sugar pine)	N. Am.	3,3	3,3	3,3	3,3	262

This aphid produces "woolly" masses on the foliage. We estimated the amount of woolly mass over an entire plot and tabulated the data as a percent of foliage infested. We assumed that the amount of woolly mass was proportional to the numbers of aphids present. The rating system adopted was: (0) no aphids on the plot; (1) light infestation--1 to 30 percent of the foliage of the plot was infested; (2) moderate infestation--31 to 70 percent of the foliage of the plot was infested; (3) heavy infestation over 71 percent of the foliage of the plot was infested. This system was sensitive to large observable differences among the species. The data are presented in tabular form, and an infestation map (fig. 1) is provided to show the extent of the infestation within the experiment area.

Table 1.--*(con.)*

Subsection and species	Continent	Blocks 1	2	3	4	Number of seedlings per species
		- - *Levels of infestation per plot*[1] - -				
		SUBSECTION STROBI				
P. monticola (Western white pine)	N. Am.	2,2,3,3, 2,1,2,2	3,3,2,3, 2,1,3,3	1,1,1,3, 2,1,3,3	3,1,3,3, 3,2,3,3	1,502
P. morrisonicola (Taiwan white pine)	Asia	0,0	0	0	0	203
P. parviflora (Japanese white pine)	Asia	0,0,0	0,0,0	0,0,0	0,0,0	116
P. peuce (Balkan pine)	Eur.	2,2,1	1,2,0	1,1,1	1,2,0	374
P. strobiformis (Southwest white pine)	N. Am.	0,0	0,0	0,0	0,0	341
P. strobus (Eastern white pine)	N. Am.	2,2	2,2	3,1	2,2	397
P. wallichiana (Blue pine)	Asia	1,3	2,3	2,3	3,3	400
		SUBSECTION BALFOURIANAE				
P. aristata (Bristlecone pine)	N. Am.	1,2	2,1	1,1	2,1	102
P. balfouriana (Foxtail pine)	N. Am.	0,0	0,0	0,0	0,0	101

[1]Ratings: 0 = no aphids; 1 = 1-30 percent of the foliage was infested; 2 = 31-70 percent of the foliage was infested; 3 = over 71 percent of the foliage was infested.

Legend: no aphid infestation; light infestation; medium infestation; heavy infestation.

Abbreviations: AL = *P. albicaulis*; AR = *P. armandii*; AS = *P. aristata*; AY = *P. ayacahuite*; BA = *P. balfouriana*; CE = *P. cembra*; CH = *P. chiapensis*; FL = *P. flexilis*; KO = *P. koraiensis*; LA = *P. lambertiana*; MN = *P. monticola*; MO = *P. morrisonicola*; PA = *P. parviflora*; PE = *P. peuce*; PU = *P. pumila*; SI = *P. sibirica*; STB = *P. strobiformis*; ST = *P. strobus*; WA = *P. wallichiana*.

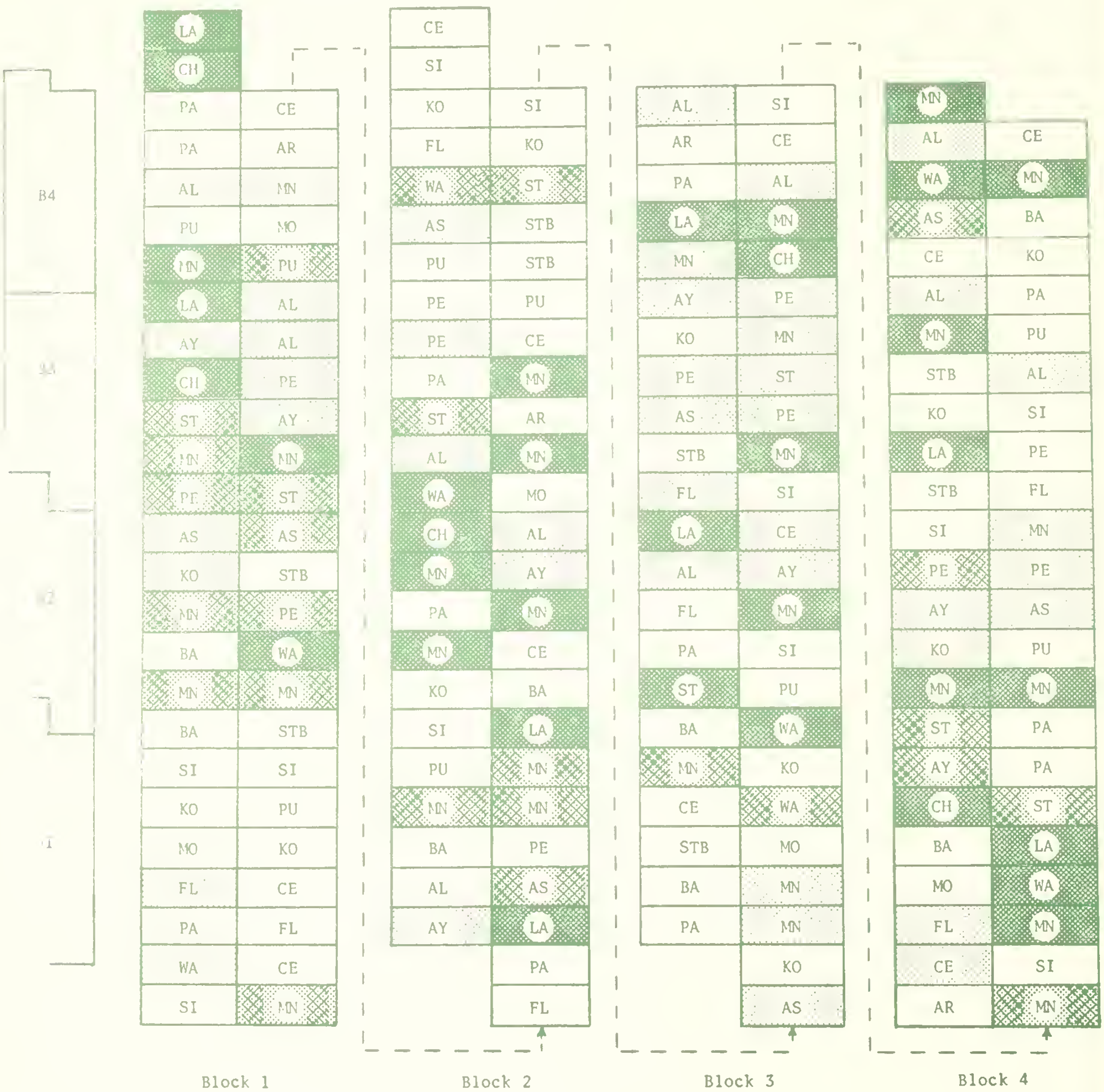

Figure 1.--Position of species plots within blocks and layout of blocks on lathhouse bench.

RESULTS AND DISCUSSION

The level of infestation of the various white pine species was strikingly different (table 1). Several species had little or no aphid infestation. Notable ones were *Pinus sibirica, P. armandii, P. morrisonicola, P. strobiformis,* and *P. balfouriana*, which had no infestation at all. Conversely, seedlings of *P. chiapensis, P. lambertiana, P. monticola, P. strobus,* and *P. wallichiana* were highly infested with aphids. The broad distribution of infested plots suggests that the entire experimental area was subjected to aphid attack. Frequently, seedlings of highly infested species grew side by side (with foliage intermingled) with completely uninfested seedlings of other species. For instance, no aphids were observed on any of the seedlings of *P. parviflora* (PA), yet 9 of the 12 plots were adjacent to species with high infestation. The aphid appears to be quite mobile and selective in picking a host. But some areas within the blocks had no aphid infestations. These could be groups of "resistant" species or escapes.

The white pines are a closely related group of species, many of which can be crossed with full fertility (Bingham 1972). Many of the species separations are arbitrary, based mainly upon geographical separation and relatively few morphological characteristics. But the separations are useful because they designate populations, some of which have been separated for millions of years.

Our interest in this group is to transfer genes that impart high resistance to white pine blister rust in species such as *Pinus armandii, P. wallichiana,* and *P. koraiensis* to species with high susceptibility such as *P. monticola, P. strobus,* and *P. lambertiana*. Knowledge concerning the presence and the levels of resistance in the white pine species has been a great aid in developing a hybridization program. Likewise, it is important to document patterns of adaptability of the same species to inland conditions to determine their potential for hybridization.

In the inland forests (eastern Washington, Idaho, and Montana), hybrids must be sufficiently cold resistant to survive temperatures as low as -40° to -50° F. Droughts also are frequent in these forests. Thirty years ago, "pole blight" damaged and killed many individual western white pines. This disease is thought to be caused by drought (Leaphart, and others 1957). On the other hand, the last three summers (1974, 1975, and 1976) were abnormally wet with the result that infection levels, and even mortality due to at least one disease, needle blight (caused by *Dothistroma* sp. and other associated insect and disease organisms), has increased. Therefore, the levels of resistance or susceptibility to many native pests and the factors that influence them in the species and hybrids in a hybridization program are also important criteria. For white pine, we hope to transfer some of the genes for resistance to blister rust--that we have not already found in the populations of the susceptible pines--from the resistant to the susceptible species. At the same time, we hope to produce a hybrid that is adaptable to the inland environment, including insects and disease pests.

The meaning of the patterns of variability in woolly aphid infestations is not immediately clear. Nonetheless, we feel the point is clear that knowledge about variability patterns in response to pests is as important to hybridization programs as knowledge about cold hardiness, drought hardiness, and other responses to the environment.

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AN AERIAL TEST OF ORTHENE AGAINST THE LARCH CASEBEARER

Richard I. Washburn, R. Ladd Livingston, and George P. Markin[1]

ABSTRACT

The larch casebearer population on test plots in Farragut State Park, Idaho, was reduced an average 97.2 percent by a systemic insectide, Orthene, sprayed from a helicopter. Tested against the needle mining stage of the casebearer, Orthene was effective when applied at a rate of 1 lb/gal/acre.

KEYWORDS: insecticides, control, larch casebearer, Orthene

The larch casebearer, *Coleophora laricella* (Hbn.), a native of Europe, was discovered on western larch (*Larix occidentalis* Nutt.) in 1957 near St. Maries, Idaho (Denton 1958). Since then, it has spread and now occurs over most of the western larch stands in Idaho. Invasion has extended into Montana, Washington, Oregon, and southern British Columbia. The Forest Service and its cooperators are placing major emphasis on establishing biological control of the larch casebearer through the introduction of several species of exotic parasites. Suppression of larch casebearer by biological control is a long-term goal.

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[1] The authors are, respectively: principal entomologist (retired), formerly located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho; entomologist, Idaho Department of Lands, Coeur d'Alene; and research entomologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Davis, California.

Chemical control using environmentally safe and effective insecticides that can be integrated with biological control is needed to protect high resource values.

Aerial spray tests of a number of insecticides, including DDT, lindane, dimethoate, phosphamidon, and malathion were conducted against the larch casebearer from 1962 to 1964 (Denton and Tunnock 1968). DDT and lindane were ineffective at dosages applied. Good control was achieved with phosphamidon, dimethoate, and malathion. Only technical grade malathion applied in the spring at 0.6 lb/acre has been registered by the Environmental Protection Agency for use against the larch casebearer.

Orthene[2], a relatively new systemic insecticide, was tested against the larch casebearer in 1974 by the State of Idaho.[3] The results of this test showed that heavy (0.75 lb/100 gal) and medium (0.375 lb/100 gal) dosages effectively reduced the casebearer population on individual trees.

In the spring of 1975, the Insecticide Evaluation research work unit (Pacific Southwest Forest and Range Experiment Station) conducted bioassay tests of Orthene against needle-mining casebearer on larch seedlings. These tests proved the needle-mining stage of the larch casebearer was susceptible to Orthene (Page and others, in press).

A test to determine the effectiveness of Orthene applied aerially on the needle-mining stage of the larch casebearer was conducted at Farragut State Park, Idaho, the fall of 1975. Those participating in the test were Potlatch Forests, Inc., Idaho Department of Lands, Pacific Northwest Forest and Range Experiment Station, and Intermountain Forest and Range Experiment Station.

METHODS

Insecticide Formulation, Application Rates

The insecticide tested was acephate (0,S - dimethyl acetyl phosphoramidothioate) which is sold as Orthene 75-S (Chevron Chemical Company 1973).

Formulation and dosage used in the field test was 1 lb of active Orthene in 1 gal of water applied at the rate of 1 gal/acre. Nigrosine dye was added at the rate of 7.6 g/gal of finished formulation to aid in the assessment of spray deposit. The spray system of the helicopter to be used was checked, calibrated, and cleared the evening before spraying.

Experimental Design

The field test involved application of Orthene from a helicopter at the rate of 1 lb/gal/acre. The test area consisted of six blocks each 20 acres in size. Three blocks, selected at random, were designated to be treated (spray blocks). The other blocks were reserved as checks (check blocks) to determine natural mortality.

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[2] Orthene is a trademark of Chevron Chemical Company. Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

[3] Livingston, R. L., and W. Ludeman. 1974. Results of an August 1974 field test of Orthene against larch casebearer. Idaho Dep. Lands, unpubl. rep., p. 8.

Treatments were made with a Bell 47G-3B-2 helicopter using a hydraulic spray system with a 36-ft boom. Thirty-two 8002 flat fan nozzles were mounted on the boom facing forward and down for maximum breakup. Seventy gallons of spray were loaded in the aircraft and used to treat the three 20-acre treatment plots, leaving 10 gal as buffer in the system. Applications were made in 50-ft swaths applied at 45 mi/h, 50 ft above treetops. Guidance was provided by marking the four corners of each plot with a fluorescent panel placed in the tree by shooting a line over the tree with a line-throwing gun and using this to hoist the panel into the treetop.

Within each of the six test blocks, 15 western larch, in an area of 3 acres or less near the center of the block, were selected for measurements of larch casebearer populations before and after spraying. The sample trees were nearly full crowned and did not exceed 35 ft in height. All blocks had an average larch casebearer population of at least 50 larch casebearer/100 fascicles.

Spray mortality counts were corrected for natural mortality using Abbott's formula where:

$$\%\ \text{control} = \frac{\%\ \text{mortality in treatment} - \%\ \text{mortality in check}}{100\% - \%\ \text{mortality in check}}$$

To determine the true effect of treatment on the larch casebearer population, a covariance analysis was run and the larch casebearer population means were adjusted.

The model used was:

$$y = \mu + x_i + B(x_{ij} - \bar{x}) + \varepsilon_{ij}$$

where:

μ = mean population

x_j = blocks

$B(x_{ij} - \bar{x})$ = covariate

ε_{ij} = error term

The null hypothesis tested was that there was no difference in the true effects among the six blocks. The Duncan Multiple Range Test was used to determine the difference between blocks.

Prespray and Postspray Sampling

Two or three days before spraying, four 18-inch branches were removed from each tree. Each branch had a minimum of 100 fascicles. The tree crowns were divided into 12 parts and each part assigned a number. Four numbers were drawn at random to determine the place from which the samples would be taken. The four branches from a tree were placed in a paper bag and labeled.

The branch samples were taken to the laboratory where they were held in a cooler at a temperature of approximately 36°F. All branches were examined within 4 days of collection. Examiners recorded the number of live larch casebearer on the 100 terminal fascicles for each branch.

The post-spray samples were collected and counted during the first 2 weeks of December after needle shedding ceased. The same procedure was used for selecting the location of branches, except that two branches were removed from each randomly selected crown position, making a total of eight branches per sample tree. Post-spray processing involved examination of overwintering casebearer larvae attached to the branches. The hibernating stage was proof that larvae had escaped the effects of spraying. The number of hibernating larvae on the 200 terminal fascicles of each branch was recorded.

Spray Deposit Assessment

Kromekote spray deposit cards were used to determine dosage per acre and spray droplet size. Two cards were used for each sample tree in all blocks. The cards were placed the morning of spraying in the nearest stand openings and at ground level. They were picked up no later than 2 hours after spraying was completed.

Deposit cards were analyzed by the Aerial Application Group of Pacific Northwest Station to estimate amount of spray deposited and determine the number of drops per square centimeter and the size of drops deposited.

Spray deposit cards were analyzed using an Imanco Quantimet 720 Image Analyzer. The system was set up with an extension tube to read an area of 0.6 cm^2 for three randomly selected areas per card. The system recorded the number of spots per area read, as well as the size of all spots over 20 μ in diameter. A 20-μ spot was formed by a droplet approximately 10 μ in diameter. Utilizing the number of droplets per area and their sizes for each pair of cards, we determined the number of droplets per unit area (number per square centimeter), the average size of the droplets and the volume of spray landing on the cards (expressed as gallons per acre).

RESULTS AND DISCUSSION

Aerial spray operation.--The deposit within the spray blocks averaged 0.34 gal/acre. This total is lower than expected and is assumed to be caused by winds that occurred during spraying. The spray drifted onto the two check blocks (II,VI) that were one-fourth mile downwind of the nearest spray block. Deposit was recorded on all cards placed in these check areas.

Droplet size in the spray blocks was larger than desired, but that measured on the cards from the check blocks II and VI was smaller and close to the desired range (table 1). Check block IV upwind from the spray blocks received no spray deposit.

Population reduction.--The corrected larch casebearer population reduction due to the spray averaged 97.2 percent for the three sprayed blocks (table 2). Statistical analysis showed that the null hypothesis was rejected with a probability level of 0.0001. The Duncan Multiple Range Test showed that larch casebearer population for sprayed blocks I, III, V, and check block VI (the check block that received the most spray drift) was significantly different (5 percent level) from check blocks II and IV.

Table 1.--*Summary of spray deposit measurements and corrected larch casebearer mortality*

Treatment and block	Corrected percent mortality	Volume mean diameter	Gallons per acre	Droplet density per cm^2	Remarks
		μ			
Spray					
I	99.6	330	0.33	5	
III	99.9	306	.47	9	
V	92.1	419	.22	1	
Check					
II	39.1	174	.01	0.7	Light drift
IV	13.5	0	.00	0	
VI	82.2	174	.01	1.0	Drift

Table 2.--*Larch casebearer pre- and postspray population densities, survival rates, and mortality estimates*

Treatment and block	Casebearer density: Prespray treatment[1] Mean	Prespray treatment[1] Standard deviation	Postspray treatment[2] Mean	Postspray treatment[2] Standard deviation	Survival ratio	Corrected percent mortality[3]
Spray						
I	47.19	41.86	0.18	1.24	0.0038	99.56
III	238.68	161.80	.15	.53	.0006	99.93
V	110.52	91.11	7.52	18.90	.0680	92.14
Check						
II	226.17	136.31	119.20	66.07	.5270	39.08
IV	202.87	131.64	175.50	95.48	.8651	13.49
VI	71.30	48.58	11.00	17.37	.1543	82.22

[1]Needle-mining larvae per 100 fascicles.
[2]Overwintering casebearing larvae per 100 fascicles.
[3]Corrected for natural mortality in check block IV.

CONCLUSIONS

Orthene shows promise as an effective insecticide for reducing larch casebearer needle mining populations.

No conclusions can be drawn from deposit-mortality relationships due to the consistently high population reduction in the treated blocks. In this test, larch casebearer population reductions were high in the blocks treated with Orthene. From the mortality that occurred in the two check blocks (II, VI) that received drift, we infer that Orthene even at relatively low concentrations kills larch casebearer.

Although this test was conducted under ideal conditions from the standpoint of casebearer population, sample tree size, access, and terrain, the material was applied under windy conditions. Nevertheless, when applied by helicopter, Orthene proved to be very effective in reducing larch casebearer needle-mining populations. Additional tests are needed to verify the effectiveness of the insecticide applied at the rate of 1 lb/gal/acre against the needle-mining stage of the larch casebearer. That mortality occurred where a light dosage (drift) was deposited would suggest future tests should also include treatments with less concentrated solutions of Orthene.

The large droplet size measured in the spray blocks is probably due to the smaller drops being blown away by the wind and, therefore, should not be taken as a measure of efficiency of the spray system used.

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SUMMARY OF NUTRIENT AND BIOMASS DATA FROM TWO ASPEN SITES IN WESTERN UNITED STATES

Robert S. Johnston and Dale L. Bartos[1]

ABSTRACT

*Summary tables are presented for aboveground biomass and nutrient concentrations for 20 aspen trees (*Populus tremuloides *Michx.) that were sampled at two study sites in Utah and Wyoming. Trees were divided into seven components--leaves, current twigs, old twigs, deadwood (branches), branches, bark, and bole wood. Samples from each component were analyzed for nitrogen, phosphorus, potassium, calcium, sodium, magnesium, zinc, iron, and percent ash.*

KEYWORDS: nutrient concentration, biomass, aspen, *Populus tremuloides*

This paper presents a compilation of aboveground biomass measurements and nutrient concentrations of three clones of aspen (*Populus tremuloides* Michx.) sampled at two study sites in Utah and Wyoming. The study is part of a comprehensive research program to investigate the dynamics and functioning of the aspen ecosystem.

Aspen has been studied extensively in the eastern United States and other parts of the world, but little work has been done on the aspen of the western United States. The current research program includes the development of a predictive model of ecosystem dynamics (Bartos 1973). Because of the lack of data, many relationships were developed by using records from other areas. The data reported in this paper were collected to validate and improve the model to make it more applicable to this region.

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Aboveground biomass, biomass distribution within each tree, and major nutrients in the various tree components were determined for 20 trees of varying size and age. The trees sampled were selected from three clones located at two sites where multidisciplinary studies of aspen ecology and management are being conducted.

SITE DESCRIPTION AND METHODS

The Chicken Creek site is located at 2,400 m elevation on the Davis County Experimental Watershed, approximately 24 km northeast of Salt Lake City, Utah. The other site, Gros Ventre, is located at 2,300 m elevation on the Bridger-Teton National Forest, approximately 48 km northeast of Jackson, Wyoming. Vegetation, soils, and topography of the Chicken Creek site were described by Johnston and Doty (1972). Vegetation and topography of the Gros Ventre site were discussed by Krebill (1972) and the soils by Bare (1972).

Individual clones at each site were identified by their phenotypic characteristics. The tree samples represented the variation in size classes within the three clones.

Fourteen trees from two Chicken Creek clones were sampled in 1973. These clones are designated Chicken Creek 3 and 4. Trees ranged in age from 16 to 91 years; the mean age of trees in each clone was about 48 years. Tree heights ranged from about 4 to 18 m and diameter at breast height (d.b.h.) from 3 to 27 cm.

The six trees sampled at the Gros Ventre site in 1974 were older, ranging in age from 94 to 151 years (average age, 116 years). Tree height ranged from 6 to 20 m and d.b.h. from 14 to 36 cm.

A total tree harvest method was used to arrive at aboveground biomass. Trees were harvested in August to make certain that maximum growth had been attained. Diameter at breast height, age, and height of each tree were recorded. If the bole was divided into manageable sections, additional diameter measurements were taken at the midpoint of each section.

Trees were felled and divided into seven components (within-tree biomass)--leaves, current twigs, old twigs, branches, deadwood, bark, and bole. A "current twig" was considered to be one with leaves and an "old twig" was defined as that portion from the bud scale scars of current growth back to the previous twig. All components were weighed in the field to determine the green weight. Each part was then subsampled to determine percent dry matter for conversion to dry weights. These subsamples were ovendried at 70° C for at least 48 hours for leaves and twigs and 336 hours, or until a constant weight occurred, for wood and bark.

Initially, 100 percent of the leaves, current twigs, and old twigs from several trees were separated in the field. After this, a small portion of the total twig and leaf components was sampled to conserve time. The calculated percentages were used to convert the total weight into appropriate parts.

Two hundred leaves were randomly selected from each tree to determine leaf area using a Lambda portable area meter. The total tree leaf area was then obtained by multiplying the mean leaf area by the calculated number of leaves per tree (total leaf weight divided by the average leaf weight).

All dried samples from the various tree parts were ground to pass through a 20-mesh screen and then subsampled for nutrient determinations. Each sample was analyzed for total nitrogen by the Kjeldahl method, phosphorus, potassium, calcium, sodium, magnesium, zinc, iron, and percent ash on a dry weight basis. Metals were analyzed by atomic absorption techniques, but other elements were analyzed according to Chapman and Pratt (1961). All determinations were made in the Soils Laboratory at Utah State University, Logan, Utah.

RESULTS

Biomass Distribution

Appendix table 1 summarizes individual tree characteristics, and related biomass measurements.

Graphical presentation of the distribution of aspen tree biomass among the seven components for each of the clones is shown in figure 1. These data are expressed as a

Figure 1.--Distribution of aspen tree biomass among seven components expressed as a percentage of the total weight.

percentage of total weight. The major portion of aboveground biomass is contained in the bole, the next largest portion in the bark, and the third largest in the branches. Leaves and current growth average 4 percent of the biomass.

Equations were developed to show the relationship between d.b.h. and total aboveground biomass for each of the study areas (fig. 2). The R^2 values were 0.997 for each curve. A single equation was developed for the Chicken Creek area by using pooled data from the two clones.

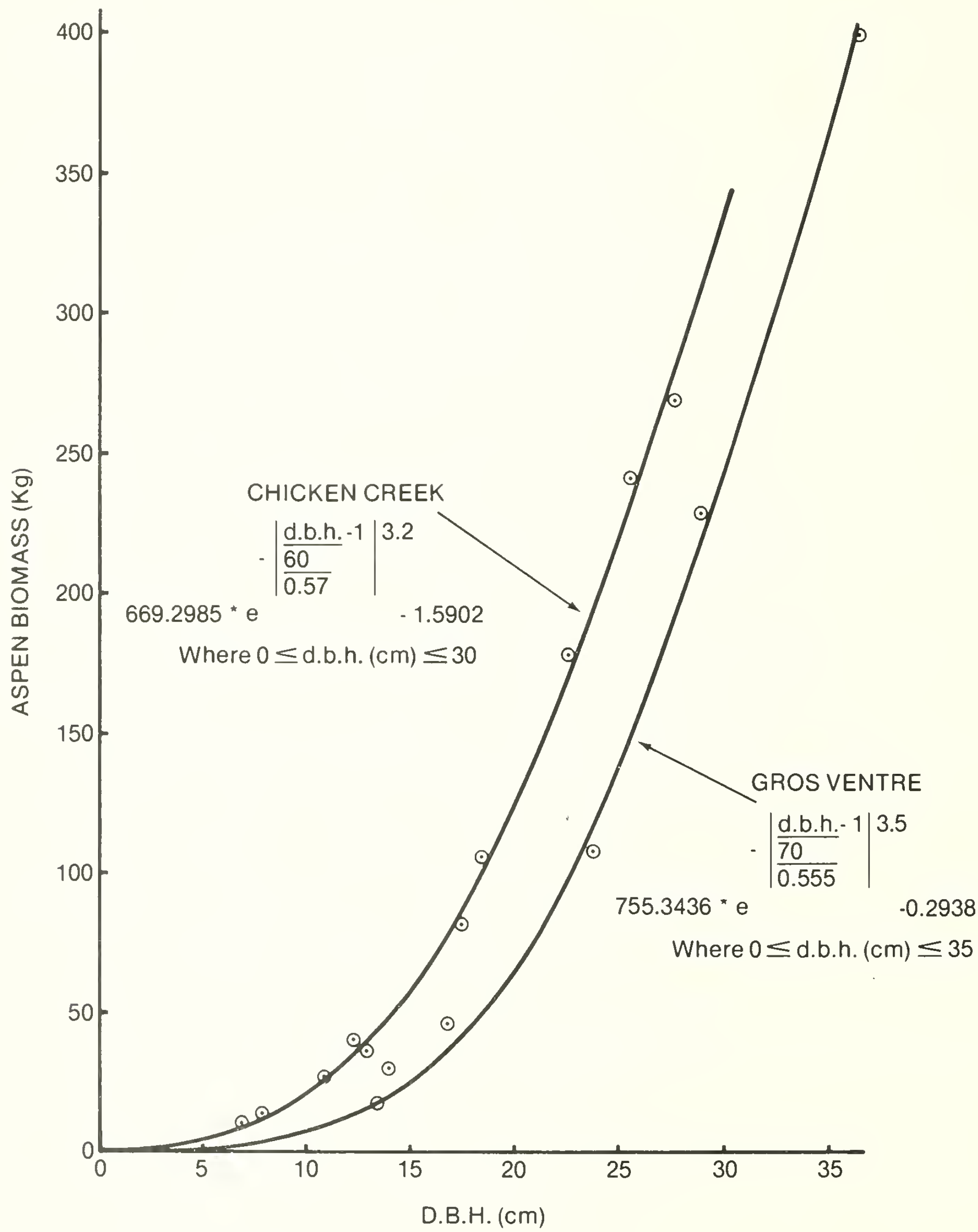

Figure 2.--Original data, predictive equation, and fitted curve for total aspen biomass for Chicken Creek and Gros Ventre Study sites.

Nutrient Analyses

All nutrient analyses for the 20 trees are summarized in appendix tables 2-8. Each table lists nutrient concentrations of each tree for a single component part. Nutrient concentrations in the bark and bole components of small trees are listed as a single entry. In large trees, these components were divided into several sections and the nutrient concentration of each section is presented.

Total content of each element per tree or component can be derived by multiplying the elemental concentration by the corresponding dry weight of the component to provide a weighted value.

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APPENDIX

Table 1.--*Summary of individual tree characteristics and related biomass measurements*

Tree No.	D.B.H.	Height	Age at d.b.h.	Leaf area	Leaves	Current twigs	Old twigs	Branch	Dead wood	Bark	Bole	Weight total
	cm	*m*		*cm*^{2}	- - -	- - -	- - -	- - *kg* - -	- - -	- - -	- - -	- - -
						Chicken Creek 3						
1	7.9	8.6	27	53,116	0.416	0.034	0.162	1.404	0.150	3.503	8.555	14.224
2	10.9	10.4	30	132,096	1.197	.078	.260	3.240	.202	7.056	14.319	27.352
3	3.3	4.0	25	6,277	.048	.003	.019	.058	.007	.468	1.146	1.749
4	3.0	4.8	16	19,608	.129	.031	.015	.095	.073	.371	.957	1.671
5	27.4	17.1	91	344,802	4.466	.330	1.266	39.840	5.088	61.627	157.028	269.645
6	18.3	16.0	71	89,308	1.170	.113	.235	8.880	.564	25.690	68.719	105.371
11	22.3	17.7	71	330,476	3.662	.264	([2])	22.021	.846	39.882	111.846	178.521
						Chicken Creek 4						
7	25.4	11	88	--	4.494	.507	1.120	55.220	35.250	46.262	99.173	242.03
8	17.3	8.5	60	196,803	1.641	.198	.516	16.128	6.080	19.130	38.546	82.24
9	12.7	8.6	50	--	←--------	2.001	--------→	5.170	2.280	8.827	18.316	36.60
10	12.2	8.7	51	188,729	1.425	.174	.624	6.985	2.426	8.613	20.524	40.77
12	3.8	3.8	29	23,820	.168	.015	.058	.217	.133	.609	1.390	2.59
13	6.9	5.8	31	51,615	.782	.103	.260	1.925	.079	1.982	5.589	10.72
14	4.3	3.8	29	29,463	.240	.017	.053	.560	.053	.787	1.514	3.22
						Gros Ventre						
1	23.6	10.4	[1]167 (200)	332,866	2.440	.200	.758	25.264	5.202	22.490	51.033	107.39
2	28.7	16.0	104	329,140	3.158	.501	1.732	26.827	5.090	39.650	151.507	228.46
3	16.8	11.7	99	92,418	.741	.063	.235	4.104	2.108	8.828	29.364	45.44
4	36.0	20.4	143	459,178	3.547	.876	1.392	72.620	18.295	64.647	238.365	399.74
5	14.0	12.0	71 (100)	82,398	.568	.070	.266	3.440	2.858	4.168	19.134	30.50
6	13.5	6.3	30 (80)	54,007	.449	.046	.104	1.651	1.220	4.849	9.526	17.84

[1] Age to heartrot - estimated age in parentheses.

[2] Old twigs included with branches on tree 11.

Table 2.--*Nutrient concentration for the leaf component for 20 aspen trees*

Tree No.	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	- - -	- - -	- - -	- - -	- - $\mu g/g$ - -	- - -	- - -	- - -	%
				Chicken Creek 3					
1	25,250	1,500	36	9,850	10,750	2,700	77.5	180	5.58
2	23,850	1,700	37.5	9,750	13,050	2,500	62.5	148.5	5.78
3	25,000	1,650	44.5	9,350	14,800	3,200	80	99.5	5.99
4	27,750	2,500	38.5	10,100	14,500	2,950	90	165	6.45
5	23,400	1,400	49	7,900	10,550	2,250	100	122.5	5.00
6	21,250	1,350	42	9,700	10,300	2,100	165	89	5.41
11	23,050	1,550	43.5	9,050	10,800	2,400	157.5	97	5.27
				Chicken Creek 4					
7	23,700	1,650	46	10,600	11,650	2,100	100	60	5.76
8	23,400	1,550	46.5	9,900	11,950	2,300	65	71.5	5.57
9	--	--	--	--	--	--	--	--	--
10	23,900	1,500	45.5	11,200	11,400	2,150	107.5	60.5	5.74
12	22,300	1,500	65.5	9,600	13,000	3,150	125	63.5	6.15
13	23,900	1,700	49.5	10,050	13,250	2,450	172.5	65	6.47
14	20,500	1,700	60	15,450	11,400	1,950	115	66	6.86
				Gros Ventre					
1	24,650	1,950	26	9,200	9,850	3,300	51.5	90.5	5.10
2	26,250	2,200	27	15,250	8,050	1,750	68.5	77.5	5.67
3	26,850	2,200	23	13,450	9,250	2,950	52	80.5	5.74
4	29,000	2,300	23.5	18,500	12,550	2,500	72.5	115	7.43
5	30,250	2,450	39	18,850	13,300	3,250	66	141	8.31
6	26,000	2,100	21	15,350	9,350	2,050	71.5	101	5.79

Table 3.--*Nutrient concentration for the current twig component for 20 aspen trees*

Tree No.	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	- - - - - - - - - -	- - - - - - - -	- - - - - -	- - - - μg/g	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	%
					Chicken Creek 3				
1	11,900	1,650	50.5	6,650	12,050	2,450	34.5	156.5	5.07
2	11,450	1,600	54.5	5,600	13,700	1,900	33	121.5	5.15
3*	11,150	1,600	41.5	6,900	10,050	1,800	37.5	96	4.26
4*	11,150	1,600	41.5	6,900	10,050	1,800	37.5	96	4.26
5	11,350	1,500	53	5,650	12,950	2,050	44.5	129.5	4.50
6	12,100	1,550	52	5,850	12,350	1,900	78	85.5	4.90
11	11,400	1,700	42	5,400	13,700	2,150	47	95	5.18
					Chicken Creek 4				
7	10,700	2,050	60	6,400	11,950	2,100	53.5	82	4.89
8	10,900	1,850	53	6,400	11,750	2,250	48.5	94	4.67
9	--	--	--	--	--	--	--	--	--
10	10,750	1,750	61	6,800	13,350	2,350	46	85.5	5.17
12	11,100	2,350	68.5	6,850	11,150	3,100	48	88	4.72
13	9,950	1,850	55.5	6,050	12,150	2,300	63.5	83	4.75
14	11,300	2,350	66	7,750	13,750	2,500	55	96	4.75
					Gros Ventre				
1	10,300	1,800	34	5,400	10,050	1,900	29.5	92	3.93
2	9,900	2,000	44	6,450	9,100	1,050	38	73	4.04
3	11,800	2,150	43	6,600	9,650	2,200	30.5	91	4.15
4	10,650	2,000	24	8,450	8,700	1,200	37.5	73	4.15
5	13,400	2,600	28	9,400	10,400	1,550	28.5	90	4.92
6	9,350	2,000	39	7,950	10,650	1,450	60.5	108	4.70

* Trees 3 and 4 were combined for nutrient analysis.

Table 4.--*Nutrient concentration for the old twig component for 20 aspen trees*

Tree No.	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	- - - - - - - - - -	- - - - - - - -	- - - - - -	- - - - μg/g	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	%
					Chicken Creek 3				
1	7,000	750	75	4,750	14,600	1,450	35	135.5	5.00
2	6,950	900	75.5	4,150	18,450	1,300	27.5	112	5.94
3*	6,600	800	64	3,800	16,250	1,300	35	97.5	5.24
4*	6,600	800	64	3,800	16,250	1,300	35	97.5	5.24
5	7,250	800	84	4,650	15,000	1,250	47	110	5.03
6	8,050	900	72	4,750	14,650	1,300	51	77	5.23
11	--	--	--	--	--	--	--	--	--
					Chicken Creek 4				
7	8,100	1,300	52	5,150	10,850	1,350	36	66	4.17
8	7,700	1,250	46	4,900	11,150	1,700	39.5	65.5	4.26
9	--	--	--	--	--	--	--	--	--
10	7,600	1,050	56	5,000	12,950	1,700	35.5	61	4.78
12	7,550	1,250	58	5,100	10,350	2,150	30.5	55.5	3.58
13	7,050	1,300	43	4,450	11,600	1,700	34.5	53	4.07
14	7,750	1,400	47	5,500	10,800	1,550	55	66.5	3.54
					Gros Ventre				
1	5,700	1,000	37	4,700	9,950	1,350	42.5	92.5	3.78
2	5,900	900	45.5	5,750	11,450	750	54	78.5	4.27
3	6,600	1,250	40	6,000	9,150	1,250	49	89.5	3.75
4	7,000	1,300	40	6,750	8,450	900	31	76.5	3.79
5	7,600	1,350	60	6,750	9,850	1,200	42	87.5	4.16
6	6,850	1,250	48	7,200	10,400	1,100	46	83	4.28

* Trees 3 and 4 were combined for nutrient analysis.

Table 5.--*Nutrient concentration for the branch component for 20 aspen trees*

Tree No.	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	- - - - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - - μg	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	%
				Chicken Creek 3					
1	5,050	600	51	3,050	14,850	1,150	34	119	4.72
2	5,150	650	46.5	2,650	16,050	1,050	32.5	122.5	4.97
3*	6,050	850	66	3,250	16,100	1,350	30.5	94.5	5.10
4*	6,050	850	66	3,250	16,100	1,350	30.5	94.5	5.10
5	5,150	550	55	3,000	16,650	1,000	28	115	4.04
6	5,600	500	54.5	3,000	20,300	1,000	30.5	84	6.17
11	5,100	550	55.5	2,600	17,150	1,000	21.5	85	5.33
				Chicken Creek 4					
7	5,900	700	77	3,050	13,000	1,100	15	76.5	4.31
8	5,700	700	99	3,200	17,450	1,450	29.5	78	4.78
9	--	--	--	--	--	--	--	--	--
10	5,900	700	64	3,650	14,500	1,400	22	63	4.65
12	5,700	700	67	3,000	13,900	1,700	17	55	4.41
13	5,050	650	58.5	2,650	16,800	1,500	54	69.5	5.17
14	5,950	750	75.5	3,300	15,950	1,400	27.5	68	4.98
				Gros Ventre					
1	3,700	700	26	2,650	9,900	1,050	42.5	78	3.50
2	4,850	650	22	3,700	10,950	650	19	75.5	3.63
3	3,950	750	27	2,800	8,800	1,050	38.5	80	3.30
4	4,600	800	26	3,700	8,450	800	21	78.5	2.98
5	3,750	600	22.5	2,800	11,450	1,150	20.5	86	3.58
6	4,350	650	37	3,650	11,000	900	30	84	3.77

* Trees 3 and 4 were combined for nutrient analysis.

Table 6.--*Nutrient concentration for the dead wood component for 20 aspen trees*

Tree No.	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	- - - - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - - μg	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	%
				Chicken Creek 3					
1	4,600	200	134	1,400	15,450	850	154	114.5	4.89
2	4,300	550	96.5	2,650	20,700	1,200	55	113	6.54
3*	4,400	200	68.5	1,900	11,800	900	30.5	75.5	3.70
4*	4,400	200	68.5	1,900	11,800	900	30.5	75.5	3.70
5	3,700	150	132.5	950	16,400	700	78	93.5	4.77
6	3,850	200	84	1,750	11,950	500	36.5	86	2.68
11	3,400	100	79.5	1,500	19,300	750	36	74	4.76
				Chicken Creek 4					
7	4,300	150	86	750	13,850	700	178	64	4.25
8	4,300	200	80	750	11,450	650	193	62.5	3.50
9	--	--	--	--	--	--	--	--	--
10	4,100	100	81	500	10,250	500	195	60	3.17
12	4,600	200	92	1,050	13,900	1,000	129.5	55	3.29
13	6,100	400	153.5	2,200	16,400	1,100	46	50	4.96
14	4,550	100	71.5	450	9,750	450	106	45.5	2.84
				Gros Ventre					
1	3,100	200	57	950	12,700	850	85	89	3.96
2	2,950	250	49	1,000	8,450	500	139	65.5	2.74
3	3,000	250	57	500	4,850	450	314	47	2.10
4	2,900	200	45.5	700	6,800	550	192.5	57.5	2.35
5	2,600	200	64.5	600	5,800	550	116.5	54	2.13
6	3,050	200	64	1,100	7,600	500	147	64	2.60

* Trees 3 and 4 were combined for nutrient analysis.

Table 7.--*Nutrient concentration for the bole component by section for 20 aspen trees*

Tree No.	Section	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	cm	- - - - -	- - - - -	- - - - -	- - - - -	$\mu g/g$	- - - - -	- - - - -	- - - - -	%
					Chicken Creek 3					
1	2.8	1,600	200	50.5	1,400	850	300	19	26	0.49
	6.4	1,200	100	50	850	800	300	137.5	30.5	.32
	9.1	1,100	100	44	3,350	3,250	750	14.5	25	1.58
	x̄	1,300	133	48	1,867	1,633	450	57	27	.80
2	*	1,100	100	29.5	700	600	200	21	14.5	.25
	x̄	1,100	100	29.5	700	600	200	21	14.5	.25
3	*	1,250	100	38.5	750	850	200	19	14.5	.35
	x̄	1,250	100	38.5	750	850	200	19	14.5	.35
4	*	1,400	200	24	950	600	200	65.5	18.5	.32
	x̄	1,400	200	24	950	600	200	65.5	18.5	.32
5	2.5	1,750	200	36	1,000	1,400	300	70	31	.64
	7.9	1,200	100	24	900	1,200	250	23	17.5	.45
	15.5	1,150	100	15.5	1,850	2,400	500	24	24	.84
	20.3	1,050	100	28.5	750	900	250	21.5	14.5	.28
	27.4	1,000	65	11.0	500	1,500	200	24	17.5	.37
	x̄	1,230	113	23	1,000	1,480	300	33	21	.52
6	6.1	1,450	150	73.5	1,750	850	300	36	14	.58
	15.8	1,100	100	34.5	1,550	1,750	400	20	13.5	.71
	19.3	900	45	20.5	650	1,100	200	18	12.5	.49
	x̄	1,150	98	43	1,317	1,233	300	25	13	.59
11	8.8	1,200	150	17	800	1,050	200	30	12.5	.51
	14.4	1,000	100	11	600	1,050	200	15.5	9.5	.36
	23.4	800	100	33.5	450	450	150	17.5	9	.18
	x̄	1,000	117	21	617	850	183	21	10	.35
					Chicken Creek 4					
7	3.3	3,250	550	35	1,500	3,950	400	41.5	32.5	1.50
	8.8	1,600	200	15.5	900	1,300	200	26.5	11	.50
	18.2	1,250	100	14	1,400	1,100	300	28	11	.54
	26.0	1,200	100	14	950	1,450	250	16.5	12	.43
	x̄	1,825	238	20	1,188	1,950	313	28	17	.74
8	4.1	1,850	450	110.5	1,150	1,550	400	27.5	15	.53
	6.7	1,500	200	70.5	1,000	1,050	300	25	11.5	.53
	13.0	1,300	200	32.5	1,700	2,050	450	20	15	.74
	18.2	1,350	100	44.5	1,450	1,800	400	23	14.5	.77
	x̄	1,500	238	65	1,325	1,613	388	24	14	.64
9	3.6	1,550	300	20.5	1,000	1,100	300	30.5	27	.50
	10.0	1,350	150	18.5	850	1,400	250	21.5	13.5	.41
	14.9	1,250	100	14.5	1,000	1,150	250	21.5	12	.49
	x̄	1,383	183	18	950	1,217	267	25	18	.47
10	5.7	1,500	300	31.5	1,100	1,000	300	50	13.5	.45
	9.1	1,400	200	33	1,350	1,000	300	29	14	.55
	14.0	1,200	100	21.5	600	550	150	27.5	9.5	.27
	x̄	1,367	200	29	1,017	850	250	36	12	.42
12	2.1	1,100	300	41.5	1,050	1,200	400	107.5	17	.90
	3.4	1,400	300	36.5	950	1,000	300	77.5	11	.54
	5.7	1,250	200	29.5	600	450	200	40.5	17.5	.22
	x̄	1,250	267	36	867	883	300	75	15	.55
13	3.2	1,550	450	102	1,100	650	300	30	15.5	0.41
	5.7	1,300	200	38.5	700	700	250	41.5	11.0	.44
	7.8	1,250	200	76	750	350	200	42.5	10	.26
	x̄	1,367	283	72	850	567	250	38	12	.37
14	2.7	2,300	400	20.5	1,450	500	350	71	17.5	.55
	3.6	1,200	250	17	900	950	250	70	11.5	.41
	5.8	1,650	200	18.5	750	700	150	59	11.5	.40
	x̄	1,717	283	19	1,033	717	250	67	14	.45

(con.)

Table 7.--*(con.)*

Tree No.	Section	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	cm					*µg/g*				*%*
					Gros Ventre					
	4.3	1,650	150	28	950	1,450	350	110	18.5	0.66
	6.4	1,250	<100	30	400	1,100	200	<4	10	.40
	13.2	1,100	100	50	500	950	300	10.5	9.5	.39
1	17.5	1,150	<100	24	350	1,150	300	10.5	10.5	.41
	17.5	900	150	44	500	1,150	300	20.5	10	.37
	18.8	1,200	<100	19	750	1,250	350	8.5	10.5	.45
	25.7	1,000	<100	22	350	750	200	4.5	9.5	.31
	$\bar{x}$	1,179	114	31	543	1,114	286	24	11	.43
	8.4	1,150	100	28	600	1,050	250	4.5	15	.46
	17.3	1,000	<100	17	500	1,200	200	18.5	12	.46
2	21.6	750	<100	25	400	1,000	200	7.5	12.5	.38
	26.4	700	<100	23	300	1,000	200	6.5	11.5	.38
	31.2	1,000	<100	38	450	750	100	15.5	12.5	.33
	$\bar{x}$	920	100	26	450	1,000	190	11	13	.40
	7.1	1,300	100	43	750	1,150	300	16	12.5	.52
	9.4	1,150	<100	26	500	1,050	300	5.5	11.5	.45
3	11.7	1,000	<100	40	350	1,150	300	17.5	9	.42
	13.2	850	<100	18	450	1,000	300	4.5	10	.40
	16.5	950	<100	13	950	1,000	250	4	7	.31
	$\bar{x}$	1,050	100	28	600	1,070	290	10	10	.42
	11.2	1,250	200	23	850	1,150	300	17.5	11	.55
	20.8	1,000	<100	51	550	1,150	200	8	12.5	.47
	26.7	900	100	10	650	1,250	300	9	10	.40
4	27.7	850	<100	24	450	1,300	300	24.5	12	.54
	30.2	800	<100	15	650	1,450	300	23	14.5	.53
	38.9	900	<100	33	750	1,150	300	10	11	.44
	$\bar{x}$	950	117	26	650	1,242	283	15	12	.49
	4.1	1,100	200	20	700	1,300	250	11.5	18	0.40
	8.6	850	100	21	400	1,300	300	4.5	14	.48
5	10.7	900	<100	58	500	1,350	350	16.5	12.5	.52
	13.2	1,300	150	22	1,250	1,850	500	10	15.5	.78
	$\bar{x}$	1,038	138	30	713	1,450	350	11	15	.55
	9.8	1,650	200	27	1,450	4,900	900	18.5	26	1.72
6	14.5	1,200	<100	14	1,750	4,150	850	7.5	21	1.49
	$\bar{x}$	1,425	150	21	1,600	4,525	875	13	24	1.61

* All sections combined.

Table 8.--*Nutrient concentration for the bark component by section for 20 aspen trees*

Tree No.	Section	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	cm	- - - - - -	- - - - - -	- - - - - -	- - - - - -	$\mu g/g$	- - - - - -	- - - - - -	- - - - - -	%
					Chicken Creek 3					
1	2.8	7,050	900	31	4,150	16,100	1,300	24	149.5	4.92
	6.4	5,100	650	39	3,150	17,300	1,100	23	167	5.40
	9.1	4,150	300	33	2,150	16,100	700	18	152	4.75
	$\bar{x}$	5,433	617	34	3,150	16,500	1,033	22	156	5.02
2	*	5,150	650	32.5	3,350	13,000	800	27.5	130.5	3.74
	$\bar{x}$	5,150	650	32.5	3,350	13,000	800	27.5	130.5	3.74
3	*	4,650	350	46.5	2,500	21,300	900	28.5	115.5	6.52
	$\bar{x}$	4,650	350	46.5	2,500	21,300	900	28.5	115.5	6.52
4	*	5,400	750	29.5	3,550	14,000	800	30	119	3.49
	$\bar{x}$	5,400	750	29.5	3,550	14,000	800	30	119	3.49
5	2.5	5,700	550	44.5	3,600	19,850	1,000	19	167.5	6.27
	7.9	5,400	450	43.5	2,450	21,100	1,050	14	164.5	5.36
	15.5	4,950	400	17.0	2,100	21,300	900	18	165	4.64
	20.3	4,650	350	21.5	2,150	20,700	850	14.5	171	6.10
	27.4	3,900	300	59.5	2,000	17,700	600	17.5	140.5	5.25
	$\bar{x}$	4,920	410	37	2,460	20,130	880	17	162	5.52
6	6.1	4,450	300	37	3,400	20,800	950	18	120.5	6.39
	15.8	4,400	300	52.5	2,550	20,550	750	22	129.5	6.35
	19.3	4,000	300	37	2,050	17,000	600	31.5	106.5	5.18
	$\bar{x}$	4,283	300	42	2,667	19,450	767	24	119	5.97
11	8.8	5,150	450	27.5	2,350	17,100	1,050	25.5	133	4.96
	14.4	4,950	450	27.5	2,450	17,400	900	84	132.5	5.23
	23.4	4,000	300	33	2,500	16,650	600	24	121	4.35
	$\bar{x}$	4,700	400	29	2,433	17,050	850	45	129	4.85
					Chicken Creek 4					
7	3.3	6,550	750	50	3,800	13,650	1,100	33	107	4.41
	8.8	5,850	550	37	2,450	15,850	1,300	14.5	121	4.55
	18.2	5,350	500	34.5	2,350	15,600	1,250	20.5	124	4.74
	26.0	5,350	450	38.5	2,500	16,100	1,200	16	137	5.01
	$\bar{x}$	5,775	563	40	2,775	15,300	1,213	21	122	4.68
8	4.1	6,100	850	49	3,200	19,600	1,800	13	149	6.39
	6.7	5,800	600	39	2,650	18,800	1,700	23	142	5,83
	13.0	4,800	400	42	1,950	18,750	1,400	28	121	5.59
	18.2	4,250	350	42.5	2,400	17,050	1,050	13.5	109.5	5.16
	$\bar{x}$	5,238	550	43	2,550	18,550	1,488	19	130	5.47
9	3.6	6,350	800	42	4,100	13,950	1,500	29.5	139	4.66
	10.0	4,950	500	74.5	2,200	15,300	1,200	22	126.5	4.59
	14.9	4,550	400	47	2,650	14,950	1,100	13	104.5	4.55
	$\bar{x}$	5,283	567	55	2,983	14,733	1,267	22	123	4.60
10	5.7	5,600	500	26.5	2,400	15,300	1,600	24	106.5	4.79
	9.1	6,350	750	38.5	3,150	14,050	1,450	16.5	126.5	4.63
	14.0	4,450	300	55.5	2,400	15,500	1,000	14	97	4.53
	$\bar{x}$	5,467	517	40	2,650	14,950	1,350	18	110	4.65
12	2.1	9,100	950	125	3,400	18,250	2,000	24	106	5.85
	3.4	5,700	650	57	3,200	16,950	1,600	22	113.5	5.56
	5.7	4,850	500	46	2,400	16,250	1,150	72	100.5	5.03
	$\bar{x}$	6,550	700	76	3,000	17,150	1,583	39	107	5.48
13	3.2	7,600	700	162.5	3,650	15,000	1,700	24.5	121.5	4.79
	5.7	6,600	700	87	2,900	15,000	1,450	78	373	4.56
	7.8	4,100	400	42	2,450	15,200	900	13	101.5	4.48
	$\bar{x}$	6,100	600	97	3,000	15,067	1,350	39	199	4.61
14	2.7	11,000	950	91	4,200	17,250	1,650	78	143	4.40
	3.6	7,000	650	64	3,300	19,050	1,600	80	135	4.48
	5.8	5,000	500	45	2,400	16,450	1,100	58.5	109	4.84
	$\bar{x}$	7,667	700	57	3,300	17,583	1,450	72	129	4.57

(con.)

Table 8.--*(con.)*

Tree No.	Section	N	P	Na	K	Ca	Mg	Fe	Zn	Ash
	cm				µg/g					%
					Gros Ventre					
	4.3	4,300	700	26	2,650	20,850	1,500	20.5	168.5	6.31
	6.4	4,050	450	26.5	2,200	23,750	1,300	14	158.5	6.95
	13.2	3,750	500	21.5	2,250	15,950	1,400	19	130.5	5.03
1	17.5	3,900	500	25	2,350	14,100	1,400	9.5	141	5.17
	17.5	3,850	500	23.5	2,150	17,250	1,350	22.5	160	5.44
	18.8	3,400	450	17	3,000	19,300	1,250	24.5	130	6.73
	25.7	3,800	800	20.5	4,800	12,050	1,400	28.5	108.5	5.16
	$\bar{x}$	3,864	557	23	2,771	17,607	1,371	20	142	5.83
	8.4	5,950	700	26.5	3,400	8,450	900	17	131	2.90
	17.3	5,850	650	19	2,950	10,500	1,050	21	143.4	3.63
2	21.6	4,900	550	21	2,900	11,300	1,050	16	140	3.85
	26.4	4,050	600	24	3,150	12,450	900	26	136.5	4.06
	31.2	4,300	750	29	5,350	13,150	900	38.5	124	4.78
	$\bar{x}$	5,010	650	24	3,550	11,170	960	24	135	3.84
	7.1	4,600	600	18	3,000	16,650	1,500	14.5	134.5	5.51
	9.4	3,950	500	36	2,150	14,850	1,500	34	139.5	5.56
3	11.7	3,650	500	23	2,200	15,950	1,400	13.5	147.5	5.73
	13.2	3,300	350	22	1,750	20,500	1,300	13	146.5	6.05
	16.5	3,200	600	36	2,650	13,550	1,400	16	115	5.15
	$\bar{x}$	3,740	510	27	2,350	16,300	1,420	18	137	5.60
	11.2	5,700	750	19	3,350	10,250	900	20	117.5	3.51
	20.8	5,550	750	123.5	3,250	10,550	1,250	14	131	3.77
	26.7	5,600	750	20.5	3,450	12,950	1,550	15	144	4.64
4	27.7	4,650	650	106	3,300	12,350	1,400	32	138	4.34
	30.2	4,700	600	28	2,850	13,050	1,650	16	145.5	4.35
	38.9	4,550	750	31	5,000	11,700	1,900	23	121	4.94
	$\bar{x}$	5,125	708	55	3,533	11,808	1,442	20	133	4.26
	4.1	5,000	1,000	27	3,650	17,550	1,600	56	158	5.72
	8.6	4,750	800	26	3,000	17,100	2,200	36	183	5.47
5	10.7	4,150	600	22.5	2,650	16,800	1,950	33.5	177.5	5.60
	13.2	5,000	750	23	3,250	16,700	4,150	36.5	140	5.75
	$\bar{x}$	4,725	788	25	3,178	17,038	2,475	41	165	5.64
	9.8	5,000	500	19.5	3,050	13,900	1,100	16	181.5	4.89
6	14.5	4,100	500	25	3,850	17,050	1,000	22	167.5	5.39
	$\bar{x}$	4,550	500	22	3,450	15,475	1,050	19	175	5.14

* All sections combined.

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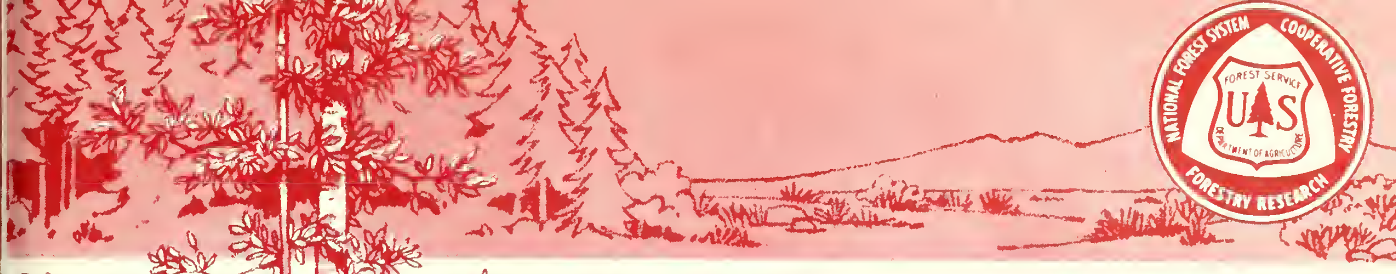

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OPENING TEMPERATURES IN SEROTINOUS CONES OF LODGEPOLE PINE

David A. Perry and James E. Lotan[1]

ABSTRACT

Cones from 13 lodgepole pine trees classified as closed-cone (serotinous), open-coned (nonserotinous), or intermediate (both kinds of cones on one tree) were immersed in water baths to determine temperature range of cone opening. Results were as follows: closed cones, 45° to 60° C; open cones, room temperature (25° C) to 50° C; and intermediate cones, 35° to 50° C. At least some cones thought to be "open" may, in fact, be serotinous cones that open at low temperatures.

KEYWORDS: lodgepole pine, cone serotiny

A serotinous cone is usually defined as one that does not open at maturity. Throughout much of its Rocky Mountain range, lodgepole pine (*Pinus contorta* var. *latifolia*) is characterized by this trait which is generally believed to be a genetic adaptation to frequent fires (Critchfield 1957; Lotan 1967; Teich 1970; and Perry and Lotan[2]).

Serotiny may be broken by high temperatures. Clements (1910) found opening to range from 40° to 69° C. Cameron (1953) extracted from cone tips material that melted in the range 44.5° to 49.0° C. Crossley (1956) reported a minimum opening temperature of 45° C. Armit (1964) found that cone-opening temperatures varied from 42° to 54° C, with distinct variations between individual trees in the temperature required for cone opening.

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[2]Perry, David A., and James E. Lotan. Cone serotiny of lodgepole pine: a possible indicator of fire history in the Rocky Mountains. Paper given at 1977 meeting of AAAS, Denver, Colo.

Cone serotiny is both an important aid in reforestation and a manifestation of differing adaptive strategies which have evolved within lodgepole pine populations. Further knowledge concerning the nature of this phenomenon may lead to better understanding and management of the species.

We report here laboratory tests of opening temperatures among the cones of 13 lodgepole pine trees from three widely scattered populations. These tests suggest that classification of cone types into either "open" or "closed" may be an oversimplification.

METHODS

New, unopened cones and old, closed cones were collected from a total of nine trees located in Idaho (Nezperce National Forest) and Washington (Colville National Forest). Three of the trees were classified in the field as closed-cone (serotinous) trees, four as open (nonserotinous), and two as intermediate in cone habit (closed-cone trees have 90 percent or greater, open-cone trees 10 percent or less, and intermediates between 10 and 90 percent closed cones [Lotan and Jensen 1970]). Cones were stored in a refrigerator at approximately 3° C for several weeks, removed and stored at room temperature (24° C) for an additional 3 to 4 weeks. Following each of these periods, the number of cones with at least one cone-scale bond ruptured, and the number fully opened, were counted. Cones that were not fully opened were immersed (about 20 at a time) in a water bath. For each set of cones, temperature of the initial bath was set at 35° C. Cones were kept in the water for 2 minutes, removed, and the number with one cone scale open were counted, along with the number that were fully opened. The temperature of the bath was then raised 5° C, and cones that had not fully opened were reimmersed for 2 minutes, after which open scales were again counted. This same procedure was followed, increasing the bath temperature 5° C each time, until all cones were fully open.

To better resolve opening temperatures, we used a water bath with more sensitive temperature control. We collected a mixture of old and new cones from three closed-, one open-, and one intermediate-coned trees in the Gallatin National Forest (Montana). These were heated at 1° ± 0.5° C intervals. Cones were counted as previously described. The number of cones tested averaged 108 per tree (range 33 to 201) for the Idaho and Washington sources, and 28 per tree (range 24 to 30) for the Montana source.

RESULTS AND DISCUSSION

Serotinous-, intermediate-, and open-type cones fall into three distinct groups with respect to cone-opening temperatures (fig. 1), each with considerable variation (fig. 2). Most cones from serotinous trees opened in the range 40° to 60° C; from nonserotinous trees, room temperature to 50° C; and from intermediate trees, 35° to 50° C. The temperature at which all cones of a given serotinous tree were open (or beginning to open) varied from 45° to 60° C. This is not attributable to population variation because the trees at either extreme are from the same area (Montana). These results support the findings of Armit (1964), who reported that closed cones do not open in a narrow temperature range.

Cone opening of four open-coned trees was temperature dependent. The fifth tree had 2 percent open during refrigerator storage, and 100 percent open at room temperature. Although this may have been due to slow drying, our results indicate that, for at least some trees, the open-cone habit is due to a relatively low temperature requirement for cone opening.

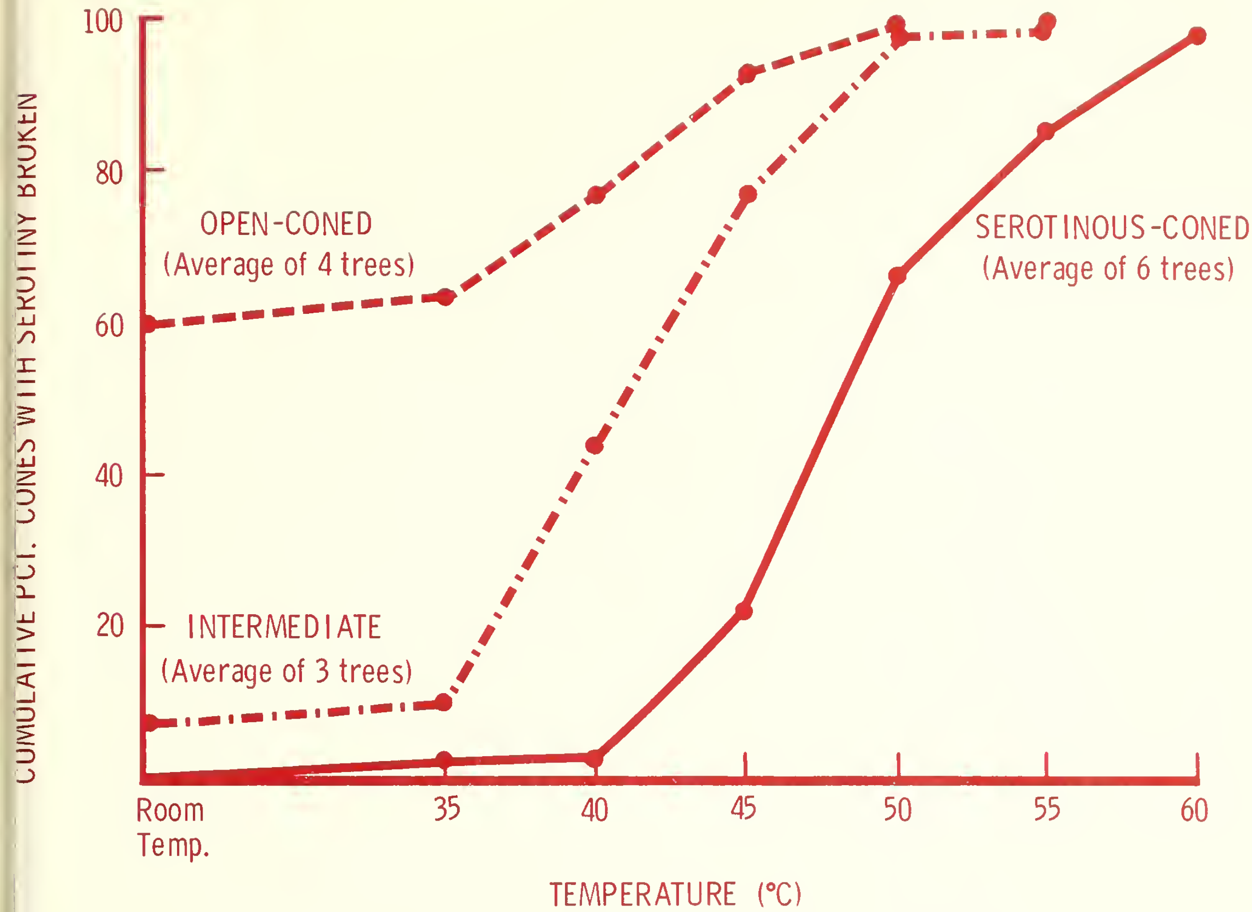

Figure 1.--Temperature dependence of cone-scale opening for trees classified in the field as serotinous, intermediate, or open in cone habit. "Cone-scale opening" is defined as the point at which at least one scale on a cone has broken its bond and opened. Full cone opening generally followed within 5° C.

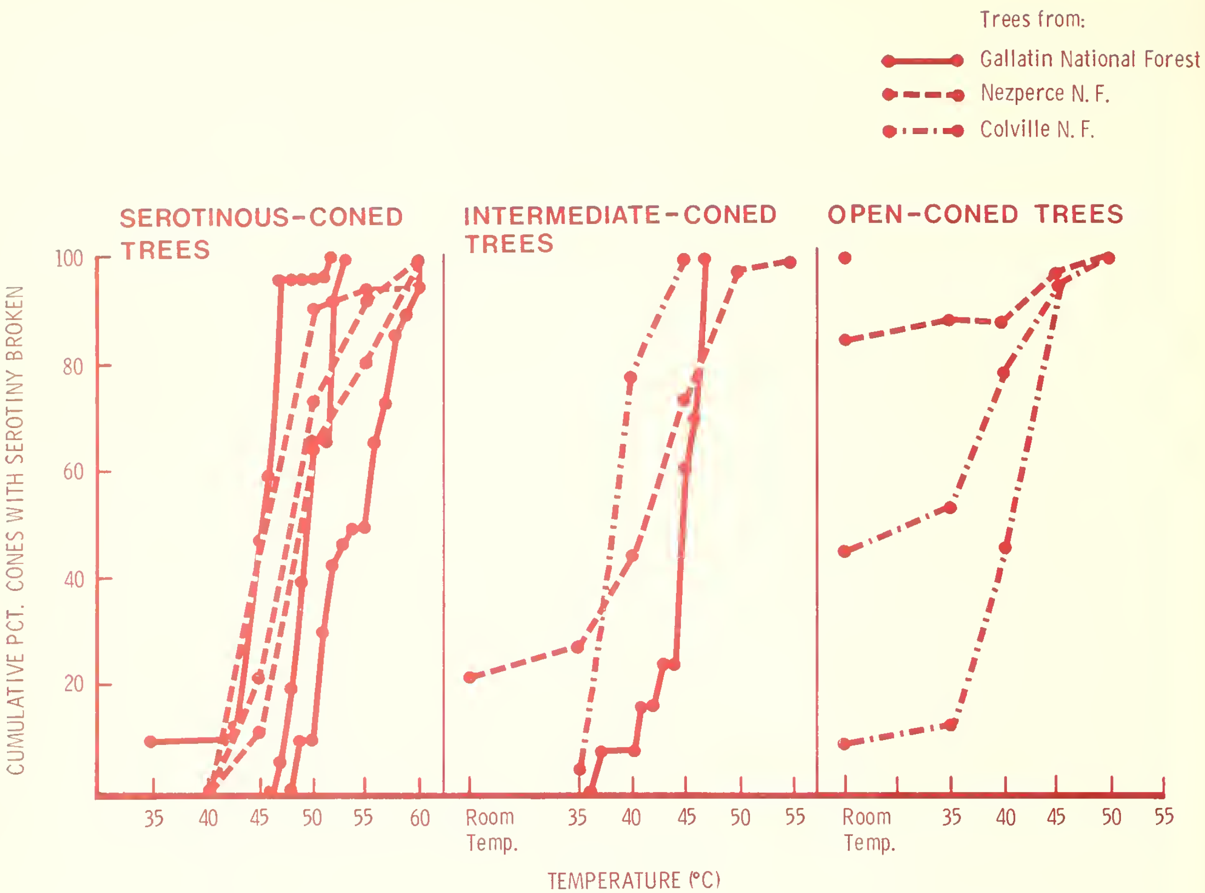

Figure 2.--Temperature dependence of cone-scale opening for cones from individual trees, by cone habit and geographic locale of tree (each curve represents data from a single tree).

Natural variation in serotinous cone opening could come from interaction among three factors: differences in scale tension, effect of environment on bonding strength, and genetic differences in bonding agent. The varying degrees of asymmetry among lodgepole pine cones might lead one to suspect mechanical differences as a major source of variation. However, the pattern of scale opening was not consistently related to cone morphology in our tests (although cones from the same tree tended to behave similarly). Further, Lotan (1970) has shown that variation in the flexing force of individual scales is only 4 percent of the force required to open a bonded scale, suggesting that differential mechanical stresses due to cone asymmetry play only a small role in scale opening.

Phenotypic expression is thought to result from an interaction between genetic and environmental factors, so environment probably influences differential expressions of serotiny. The question is, to what degree? Lotan (1975) and Crossley (1956) have shown some correlations between serotiny and elevation. Thompson (1969) found fewer serotinous cones on the south side of two trees than in other directional quadrants. Crossley (1956), on the other hand, found no difference in the serotiny of trees on north- and south-facing aspects, and concluded that this implied a lack of environmental effect in cone opening. Similarly, we found no apparent correlation between the various opening temperatures and the aspect of the trees from which cones were collected.

In this study, the opening temperature of old and new cones from the same tree was different. In some trees, old cones opened at a higher temperature, and in some, at a lower. Lotan (1970) found no correlation between cone age and force required to open scales, suggesting that the melting characteristics of the resin seal may be modified by environment during the period of cone maturation.

The genetic and environmental factors controlling the expression of cone serotiny in lodgepole pine are complex and poorly understood. It seems probable that our genetic and working classification of trees into open, intermediate, and serotinous is an oversimplification. This study suggests not two distinct types of cones--those that require heat to open and those that do not--but rather cones with a very wide range of opening temperature requirements. The intermediate tree may not be simply one with some open and some closed cones, but rather one whose range of cone-opening temperatures falls within the range of environmental temperatures experienced in the crown.

This report merely raises questions about the nature of cone serotiny in lodgepole pine. Although too small to provide answers, the data base suggests that cone opening temperature varies widely among serotinous cones. Some cones thought to be "open" may, in fact, be serotinous cones that open at low temperatures. Only by collecting more data from a wide geographic area can we gain better understanding of this phenomenon.

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Research Note INT-229

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PRELIMINARY GUIDELINES FOR PRESCRIBED BURNING UNDER STANDING TIMBER IN WESTERN LARCH/DOUGLAS-FIR FORESTS

Rodney A. Norum[1]

ABSTRACT

Guidelines are offered for safe, effective fire treatments in western larch/Douglas-fir forests. Describes procedures for estimating and limiting the scorching of tree crowns. Provides a method for predicting percentage of the forest floor that will be burned down to mineral soil.

KEYWORDS: fire management, prescribed fire, fire prescriptions, understory burning, firing techniques.

To successfully conduct a broadcast prescribed fire beneath standing trees, some means must be found to limit fire intensity and yet provide a desired treatment. By using a form of firing that will control the release of heat along with careful selection of burning conditions, a safe and successful fire beneath standing timber is possible. In a typical western larch/Douglas-fir forest (SAF-212), considerable care must be taken when planning the ignition pattern and when selecting and waiting for the correct burning conditions. Less care may be required in other forest situations such as in large, widely spaced ponderosa pines, with light fuel loadings beneath, or perhaps in a western larch seed tree cut where the residual trees are massive, fire-resistant old veterans. Even in these cases, control of fire intensity and attention to burning conditions are advisable. In yet other forests types, such as lodgepole pine or spruce stands, extreme care must be used if the residual stand is to be kept alive. The guidance offered here is most suitable for old-growth western larch/Douglas-fir stands, either in natural condition or where harvested by partial cutting. The duff reduction information applies equally well on clearcut, uncut, or partially cut areas that are broadcast burned.

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HOW TO BURN UNDER STANDING TIMBER

Burning Patterns

Heat can be dispersed by means of a firing pattern that consumes fuel in controlled amounts and that releases heat slowly and evenly. Probably the best means of firing in the understory in the western larch/Douglas-fir types is a series of strictly limited strip headfires. As the name suggests, strips of fuel are ignited and burned out, beginning at the upslope end of the fire area, or the downwind end if the terrain is flat. Once a strip has burned out to a low level of fire activity, the next strip is ignited, and so forth, until the fire treatment is completed. In proper fuels a backing fire is at least as good as strip headfiring; however, fuel continuity, fuel size class distribution, and fuel moisture content are usually unfavorable for a backing fire in western larch/Douglas-fir forests. Strip headfires, *properly conducted*, are much more flexible.

Hazards

To reap the benefits of strip headfiring, two rules must be followed. First, a strip must be allowed to burn until fire intensity markedly drops before proceeding to the next strip. Second, strip width must be small enough to prevent the full flame height and width of a free-burning, forward-spreading fire from developing. If either rule is violated, damage to the stand in the form of tree-crown scorch will increase, sometimes dramatically, along with more frequent crown fires and the danger of spot fires.

Research shows that when broadcast burning in western larch/Douglas-fir stands with down, dead woody fuel loadings from 5- to 50-tons/acre, 15- to 20-foot strips is the limit for consistent control of the fire intensity. These limits should be observed and adopted where similar fuels are to be burned in this forest type. (Strips can be narrower if fire behavior indicates the need for tighter control or limitation.)

Successful understory burning in heavy down, dead, woody fuels requires patience. A strip must be allowed to burn up before another is ignited, and impatience must not lead to wider and wider strips. Patience is also needed when waiting for the correct prescribed conditions for burning.

Avoiding Crown Scorch

One means to determine the need for narrower strips is the flame height in a stand. Preliminary data indicate that Douglas-fir with 60 percent of the crown scorched will probably not survive. Western larch and ponderosa pine can apparently stand more scorch than Douglas-fir; the exact amount is unknown. Little is known about other species in the Rocky Mountains. Until studies give more explicit guidance, crown scorch in Douglas-fir should be less than 60 percent of crown length.

Albini (1975) has presented a crown scorch model (fig. 1) that relates flame length to scorch height on a standard (77° F) day. The curves represent different windspeeds. To use the curves, estimate maximum length of the flames, measure windspeed, and look up the maximum scorch height on the chart. Measure the temperature and go to figure 2 to estimate the scorch height that is occurring. For example, if the temperature is 60° F and the estimated flame length is 4 feet with a 5 mi/h wind, the maximum scorch height is about 18 feet. At 60° F, the actual scorch height is about 0.75 of maximum or about 13.5 feet. If this scorch height is less than about 60 percent of the crown of the desirable Douglas-firs, flame height is acceptable. If more than 60 percent of the crowns are being scorched, it may be possible to reduce the flame height by taking narrower strips of fuel in each strip headfire. The model will estimate scorch height for any tree species, but the limit of scorching is often not known. The author has used this technique repeatedly on fires and found it useful and sound.

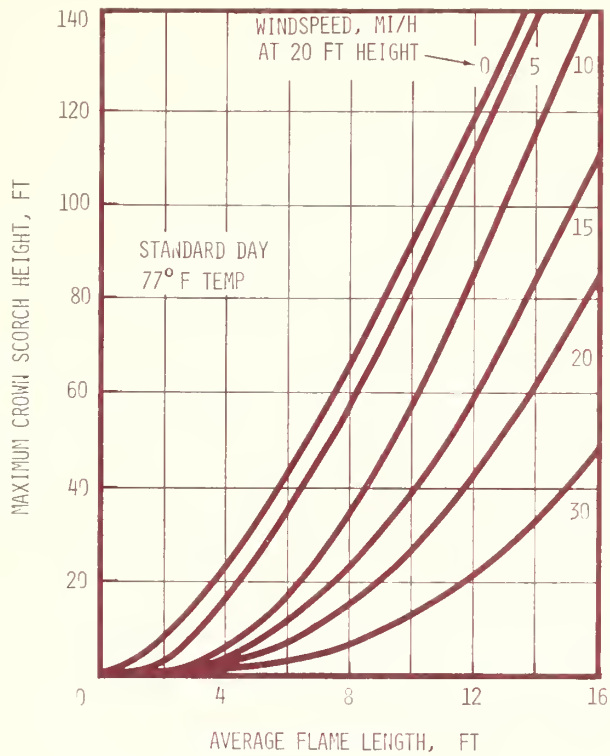


Figure 1.--Maximum height of crown scorch versus flame length on a 77° F day.

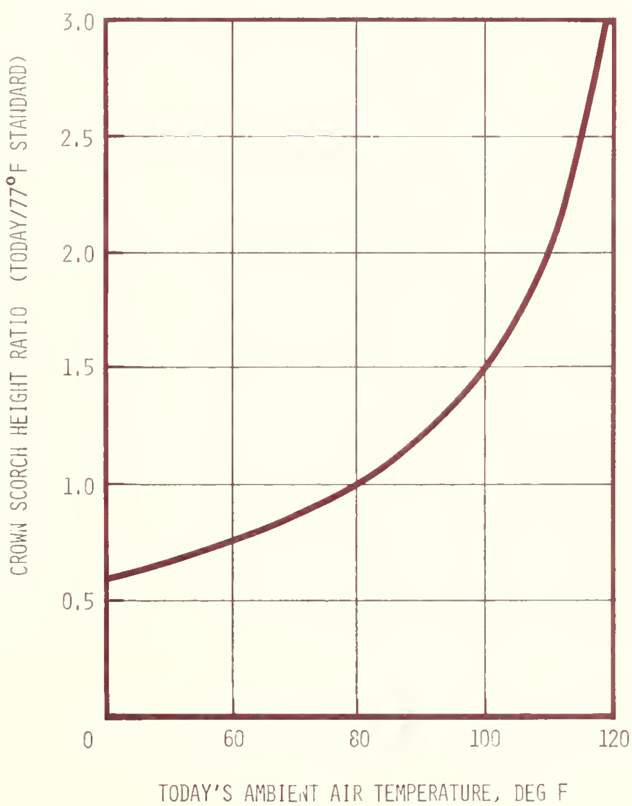
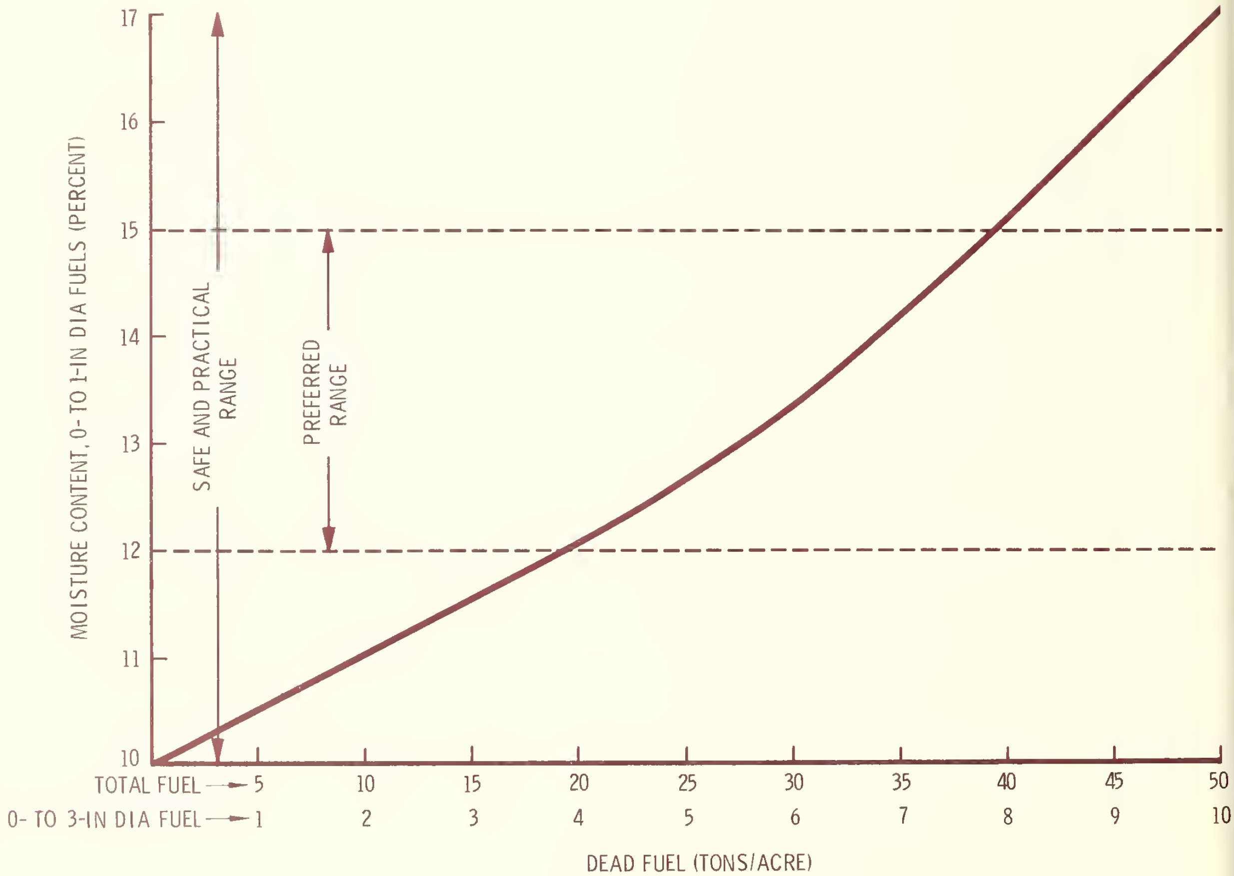


Figure 2.--Relationship of scorch height to burning-day ambient temperature.

When To Burn

Fuel moisture determines the degree to which a fire accomplishes the land manager's objectives. We must first know the range of burning conditions over which it is possible to burn, yet completely control the fire. To help answer this question, we compiled the graph in figure 3 from our experience in burning under standing timber in a large number of western larch/Douglas-fir stands. The diagonal, curved line gives various sets of fuel moistures and fuel loadings for a spreading fire that is readily controllable and not unduly damaging to overstory trees if other conditions are favorable. The fuels should be reasonably well distributed and uniform over the area. Windspeed should be below 10 mi/h, and preferably below 5 to 7 mi/h if directly upslope. At 10 percent fuel moisture content, the fire will be fairly intense and will spread readily. At 17 percent moisture content, a continuous bed of fine fuel (preferably cured, needle-bearing slash) is necessary to prevent a ragged fire treatment. This kind of burning is easiest and safest within the preferred range of fuel moisture content shown in figure 3, especially if the heavier fuel loadings are burned at or near the 15 percent level of moisture content and lighter fuel loadings around the 12 percent mark.



Fuel Moisture Content

The fuel moisture values indicated in figure 3 are for the actual fuels to be burned. Because the range of desired fuel moisture is quite narrow and highly influential, the moisture content must be taken only from fuel samples. Half-inch fuel moisture sticks tested over a period of 2 years during the burning of 24 stands were frequently in error by as much as 5 percent moisture content from that of the actual fuels. An error of this size can have a pronounced effect on fire behavior and results. Fuel moisture sticks should not be used for this kind of understory burning.

Fuel moisture can be estimated by means of conventional ovendrying techniques. Fuel moisture can also be calculated within 30 minutes of ignition by means of a microwave oven powered by a portable generator, at the site to be fired. Both techniques are outlined in the appendix. A detailed research paper on microwave oven technique is being prepared by the author. If fuel moisture cannot be estimated, the fire should not be conducted. Too much is at stake. Figure 3 lists fuel moisture for 0- to 1-inch-diameter down, dead, and woody fuels. A sampling procedure similar to the one described in the appendix should be followed.

Fuel Loadings

The fuel loading values shown in figure 3 are estimated by a planar intersect fuels inventory. The sampling density and procedure are described by Brown (1974). Two fuel load scales are shown in figure 3. If the fuel is recently created slash, logged to a 4-inch top and utilized for sound logs and poles, the total fuel load value can be used. For other cases, the 0- to 3-inch-diameter fuel load should be relied upon. (When in doubt, use the 0- to 3-inch value.)

It is not intended that only those values falling on the line in figure 3 be considered as good conditions for burning, but rather to show where burning is most safe and effective. Above 30 tons/acre total fuel load, or 6 tons/acre of 0- to 3-inch material, fuel moisture contents from 13 to 17 percent are advisable. Below these fuel loadings, the 10- to 13-percent range will give the best fires.

The foregoing describes conditions when burning under standing timber is possible and controllable without destroying a mature stand of moderately to highly fire-resistant tree species. Most trees with thin bark will be killed in any of these fires. This is true whether a tree is a young western larch or an old lodgepole pine. The fires can be safe and burn well, yet kill trees. Most Douglas-fir, ponderosa pine, and western larch larger than about 5 inches d.b.h. will survive. Most Engelmann spruce, subalpine fir, lodgepole pine, and trees smaller than about 5 inches d.b.h. will not survive. Even this will vary. The key is bark thickness and the percentage of the crown that escapes scorching temperatures.

Duff Reduction

The reduction of duff, and the baring of some mineral soil is often one of the objectives of fire treatment, especially where a seedbed receptive to certain species of trees is desired. When the duff is sufficiently dry it will burn, although quite slowly. Most often, especially during the usual seasons of prescribed burning, the duff is much too wet to burn unless a considerable amount of heat is applied from larger fuels burning above the duff. The duff is dried, ignited, and consumed to a degree dependent on how wet the duff is and how much fuel is available.

Experimental results show that duff consumption can be predicted if moisture content of the duff and fuel consumption or fuel availability can be estimated. Figure 4 shows the relationship between the percentage of duff removed and the moisture content of the lower half of the duff. Note that below about 30 percent moisture content, duff

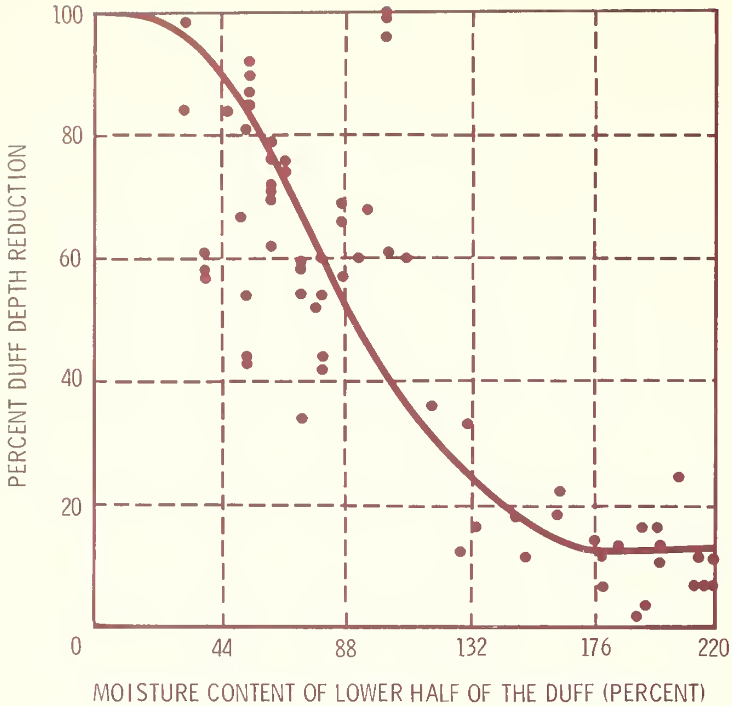


Figure 4.--Percentage of preburn duff depth reduced by broadcast fires versus the moisture content of the lower half of the duff. Curve fitted to experimental data.

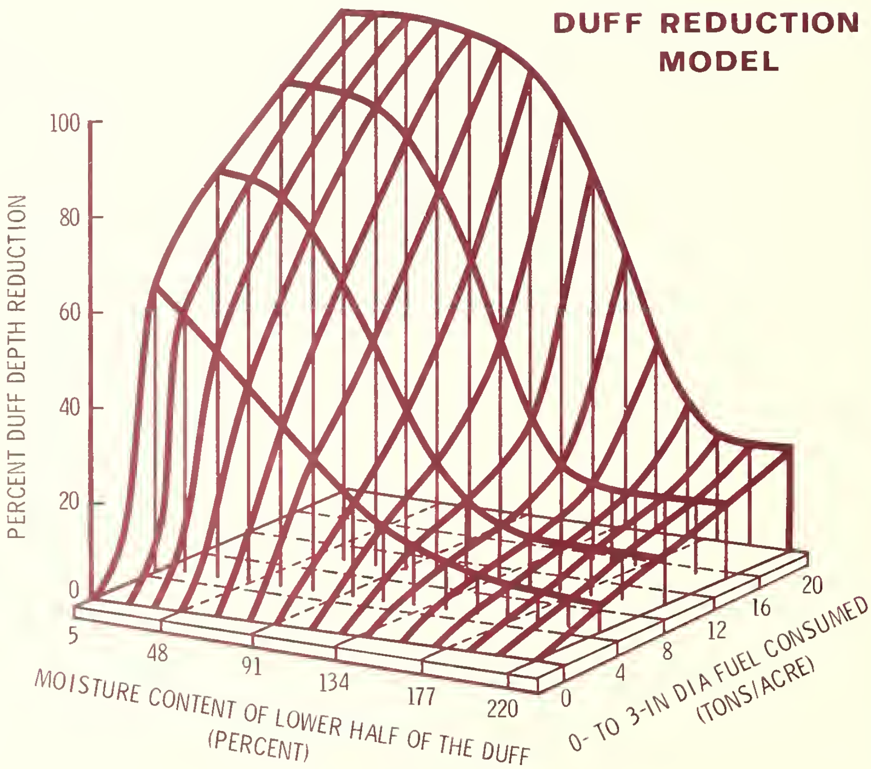


Figure 5.--Percentage of duff reduction as it varies with combinations of moisture content of the lower half of the duff and the amount of 0- to 3-inch-diameter down, dead, and woody fuels consumed.

is almost completely consumed. This agrees with the moisture of extinction value used by Albini (1976) for the closed timber litter fuel model. Presumably this is where duff will burn unassisted. As moisture content rises, the amount of duff consumed drops until, at about 150 percent, the curve flattens out, suggesting that only about 15 percent of the duff can be removed. Note also that some of the points fall well above the curve and some well below. This is a reflection of the influence of the fuels burning above the duff.

The influence of fuel consumption is more easily understood by viewing the three dimensional diagram in figure 5. This diagram was developed by fitting a mathematical model to measured data, following the procedures described by Jensen (1973). Note that the third axis is the amount of 0- to 3-inch-diameter surface fuels that burned. At any given value of moisture content in the lower duff, an increased amount of 0- to 3-inch surface fuel consumed gives an increased amount of duff consumption. This reflects the influence of the heat from fuels burning above the duff. However, as the duff gets wetter, an increasing amount of fuel is needed to reduce an equal amount of duff. When the duff is very wet, the amount of fuel burned has a severely decreased effect on how much duff will be removed.

For the convenience of the user, the relationships among the amount of duff removed, the moisture content of the lower half of the duff, and the amount of 0- to 3-inch surface fuel consumed have been tabulated in table 1. To use the table, one needs to know the moisture content of the lower half of the duff (ovendrying technique) and how much 0- to 3-inch-diameter down, dead, and woody fuel will be burned. The latter information is obtained by inventorying the fuels: the combined preburn weight of the 0- to 1/4-inch, 1/4- to 1-inch, and 1- to 3-inch size classes, as described by Brown (1974). In the range of safe and practical moisture contents shown in figure 3, the amount of 0- to 3-inch fuels consumed is estimated with surprisingly reliable accuracy by multiplying the preburn weight by 0.78. Enter the table with that value along the line entitled "0 to 3 inch fuel loss" and stop at the value closest to your result. Then read down that column for combinations of percentage of duff moisture and percentage of duff reduction. The figure indicates percentage of preburn duff depth that will be burned away.

One further finding leads to a useful means for estimating the percentage of the area that will be bared to mineral soil. Although not strictly true, the duff tends to be removed in an even layer all across a broadcast burned area in western larch/Douglas-fir stands. Anyone who has done much burning knows that some spots will burn hotter than the surrounding area. However, an analysis of several thousand duff reduction measurements on 61 broadcast-burned clearcuts and 24 broadcast fires under standing timber in western larch/Douglas-fir stands revealed that only five fires had a standard deviation in duff depth reduction greater than 1.25 inches, and that 70 percent of the fires had less than a 0.8 inch standard deviation in duff depth reduction. The assumption of a uniform layer of removed duff appears to be sound.

Table 1.--*Percentage of duff depth reduction*

Moisture content, lower half of duff	0-to 3-inch fuel loss (tons/acre) 0	5	10	15	20
			Percent		
5	0	61	79	90	100
10	0	59	78	90	100
15	0	58	78	90	100
20	0	56	78	90	100
25	0	53	77	90	100
30	0	51	76	90	100
35	0	49	75	90	100
40	0	46	73	90	100
45	0	44	71	89	100
50	0	42	68	88	100
55	0	39	65	87	100
60	0	37	62	85	100
65	0	35	58	83	99
70	0	32	54	81	99
75	0	30	50	78	99
80	0	28	45	74	98
85	0	26	41	69	97
90	0	25	37	65	96
95	0	23	33	59	94
100	0	21	29	53	92
105	0	20	26	48	89
110	0	18	23	42	86
115	0	17	20	36	83
120	0	16	18	31	78
125	0	15	16	27	74
130	0	14	14	24	68
135	0	13	13	21	62
140	0	12	12	19	56
145	0	11	12	18	50
150	0	10	11	17	44
155	0	10	11	16	39
160	0	9	11	16	34
165	0	9	11	16	30
170	0	8	11	16	27
175	0	8	11	16	25
180	0	7	11	16	23
185	0	7	11	16	22
190	0	7	11	16	22
195	0	6	11	16	21
200	0	6	11	16	21
205	0	6	11	16	21
210	0	6	11	16	21
215	0	5	11	16	21
220	0	5	11	16	21

The author has had good success in predicting the percentage of the area burned to mineral soil by using the following process. First, measure duff depth at many points scattered about the planned burn unit (100 points is a good number). Decide the percentage of the area you desire to have bare to mineral soil. Call this "Percent Bare": for example, Percent Bare = 60 percent. List preburn duff depths measured. For example:

Preburn duff depths (Inches)
4
3
2
1
0
6
5
3
4
3

For simplicity, this example has only 10 measurements, so set n = 10. To have 60 percent of the area bare to mineral soil, six sample points must be reduced to zero duff depth.

Because duff tends to be removed in an even layer, examine the list to see how thick a duff layer must be burned off to bare 60 percent of the points. Proceed as follows:

1 point is zero, or 10 percent of the area sampled.
2 points are 1 inch or less, or 20 percent of the area sampled.
3 points are 2 inches or less, or 30 percent of the area sampled.
6 points are 3 inches or less, or 60 percent of the area sampled.

Therefore, we must burn away a layer 3 inches thick. Of course, some points do not have 3 inches of duff, but if we prescribe the fire to burn away 3 inches of duff, those with less than 3 inches will be bare along with those that have 3 inches.

Compute the percentage of loss for each point if 3 inches is removed, and average the result. If the preburn depth is less than 3 inches, award 100 percent.

	Percent
$3 \div 4 = 0.75 \times 100 =$	75
$3 \div 3 = 1.0 \times 100 =$	100
2	100
1	100
0	100
$3 \div 6 = 0.5 \times 100 =$	50
$3 \div 5 = 0.6 \times 100 =$	60
$3 \div 3 = 1.0 \times 100 =$	100
$3 \div 4 = 0.75 \times 100 =$	75
$3 \div 3 = 1.0 \times 100 =$	100
Total =	860

$$\text{Average} = \text{Total}/n = \frac{860}{10} = 86 \text{ percent} = \text{needed percentage of duff loss.}$$

You can now determine if the fuel loading on the area will create a fire hot enough to burn away the desired amount of duff. As stated previously, you can estimate this by multiplying the 0- to 3-inch fuel weight by 0.78. Enter table 1 under "0- to 3-inch Fuel Loss" in the column closest to your result. For our example, assume a preburn 0- to 3-inch fuel weight of 20 tons/acre. Multiplying 20 tons × 0.78 = 15.6 tons, so enter the table under the column headed 15 tons/acre. We see that it is possible to remove 90 percent of the duff if it is at 5 percent moisture content. Our computed percent duff depth reduction was 86 percent, which would be achieved at a duff moisture content between 50 and 55 percent if we burned when the 0- to 1-inch fuel moistures are within the 10 to 17 percent range discussed earlier.

SUMMARY

For many managers, understory burning is a new experience. Mistakes are often made during first attempts because some of the fire effects are not obvious at the time of the fire. In particular, the scorching of the crowns does not become apparent until days or even weeks after the fire. The fire may have all of the appearances of going nicely, only to show a severely scorched stand a few days later. The procedures described for estimating the scorch are strongly recommended. Using these estimates the fire manager can adjust the fire as described and achieve the desired objectives with minimal damage to the stand. Ignoring these details will often lead to needless damage. Burning when the 0- to 1-inch fuels are within the recommended range will yield fires that are effective and safe. Selecting a duff moisture content of the right value will give the added benefit of removing the desired amount of the duff layer.

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APPENDIX

Sampling Fuels and Duff for Moisture Content

To use the prediction models given in this paper, the moisture contents of the 0- to 1-inch-diameter down, dead, and woody fuels and the lower half of the duff must be determined. Several samples should be taken from locations distributed across the fire areas. The 0- to 1-inch samples should be taken from about the midpoint of the depth of the fuel bed, and should be about equally divided between the 0 to 1/4 inch and 1/4 to 1 inch size classes in each sample. They should, in every way possible, represent the fuels that exist. The duff should be collected from the lower half of the duff, regardless of duff depth. Be careful to exclude any mineral soil from the duff sample. Roughly a large handful of material should be collected for each sample.

If a standard oven at 100° C is to be used to dry the fuels, a period of 24 hours is needed to determine the moisture content. Therefore, the fuels should be sampled each day for several days ahead of the fire day, taken at about the same time of day that ignition is planned. By doing so, a drying trend can be plotted on a graph, and a reasonable estimate of the fuel moisture can be projected. This scheme is frustrated if the weather conditions change during the night before or the day of the fire, but if the daily weather pattern remains consistent the procedure is reliable. As a last resort, the fuels should be sampled at least once, 24 hours before the fire, and ovendried to determine their moisture content. If the weather does not cause rapid wetting or drying, the estimate will be reasonably accurate.

A suggested procedure follows:

1. Go to the unit to be burned at about the time of day you expect to burn.

2. Collect one sample of 0- to 1-inch-diameter down and dead woody fuel from each of 10 points spread out across the unit. Ten points on a diagonal through the unit is a good pattern. Take the samples from the midpoint of the depth of the fuel bed. Put the sample in a container and seal it tightly.

3. At each point collect a sample of the lower half of the duff, avoiding mineral soil. Place in a container and seal it.

4. Transport the samples to a drying and weighing facility and weigh the wet samples. If the collection containers are deep and narrow (like a test tube), it is advisable to transfer the samples to wider, more open containers before weighing and drying. Record the weight of the container of wet fuel to an accuracy of 0.1 gram.

5. Dry the fuels in a 100° C oven overnight (approximately 24 hours).

6. Remove the dried samples from the oven, one at a time, and quickly weigh again to an accuracy of 0.1 gram. Record the weight of the container of dry fuel.

7. Discard the fuels, weigh the drying container and record it as "tare" weight.

8. Calculate the fuel moisture content as follows:

   a. Subtract the tare weight of the container from the weight of the container of wet fuel and call this "wet weight"; wet + tare - tare weight = wet weight.

   b. Do the same for dry weight: dry + tare - tare weight = dry weight.

   c. Calculate moisture content:

$$\%\ \text{moisture content} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

Figure 6 shows a sample form for calculating moisture content of fuels.

FUEL MOISTURE CONTENT

UNIT____________

DATE____________

NAME____________

Sample I.D.	Wet + tare	tare	Wet wt.		Dry wt. + tare	tare	A Dry wt.		B Diff	C M.C.		$C = \frac{B}{A}$		

Figure 6.--Sample form for calculating ovendry moisture content of fuels.

The procedure for using a microwave oven is similar, but certain precautions are necessary. Further, because the drying can be accomplished in about one-half hour, the fuels can be sampled shortly before ignition is planned, and the decision to burn can rest on the results.

The weighing procedure is the same as described before, as are the calculations. To dry the samples, place them in weighed, *nonmetallic* containers. Wide, flat glass containers work well. Place the samples in the microwave oven. It is also very important that you place 3 or 4 moistened sponges in the oven in order to avoid damage to the oven as the samples become dry. Turn the oven on for 3 minutes. Turn the oven off and stir each sample, using a piece of wire or a glass rod. Be careful that no sample material spills from the container or sticks to the stirring rod. Repeat the process seven or eight times to be sure all moisture is driven off. Keep the sponges damp throughout the process. Proceed with the weighing procedure and calculations as previously discussed for standard ovendrying.

The following safety precautions should be observed.

Medical authorities feel that microwave ovens may interfere with the normal operation of medical electronic devices, such as cardiac pacemakers. Consequently, people using such devices should not operate microwave ovens.

Other safety practices recommended are:

1. Have oven tested at least once a year for radio frequency leakage.

2. Do not use the oven if the door does not close and latch firmly against the oven front.

3. Periodically check door for worn hinges, torn or twisted door seal, and any other visible sign of damage.

4. Do not try to use the oven with the door open and do not attempt to defeat any interlocks.

FIRE IN MULTIPLE USE MANAGEMENT RD&A PROGRAM

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ARIZONA TIMBER PRODUCTION AND MILL RESIDUES, 1974

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ABSTRACT

1974 Arizona roundwood timber production was 78.9 million cubic feet, down from the 1969 estimate of 88.5 million cubic feet. Round pulpwood production was 7.9 million cubic feet, up from 7.6 million cubic feet in 1969. The estimated volume of residues from sawmills was 33.9 million cubic feet, of which 86 percent was used.

KEYWORDS: primary wood products, sawtimber, pulpwood, sawmill residues use

In 1974, timber production in Arizona was nearly 79 million cubic feet, a decline from 1966-1969 levels (about 88.5 million cubic feet) that were reached at the peak of an upward trend that began in 1952 (fig. 1).

Saw logs continued to be the predominant product, accounting for about 72 percent of the volume of all roundwood harvested (table 1). The 56.7 million cubic feet (363.2 million board feet)[1] of saw logs were about 14 percent less than 1969 production of 66.1 million cubic feet.

Pulpwood volume continued to increase with 1974 production up 4 percent from 1969 to 7.9 million cubic feet. Production of all other roundwood products combined decreased about 3 percent from 1969.

Most of the volume of saw logs received at mills (about 312 million board ft.) was ponderosa pine (table 2). Douglas-fir mill receipts totaled about 21 million board feet. Volume of other species, including Engelmann spruce and true firs, was about 30 million board feet.

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[1]International 1/4-inch log rule is used throughout this report for board-foot volumes of roundwood, unless otherwise specified.

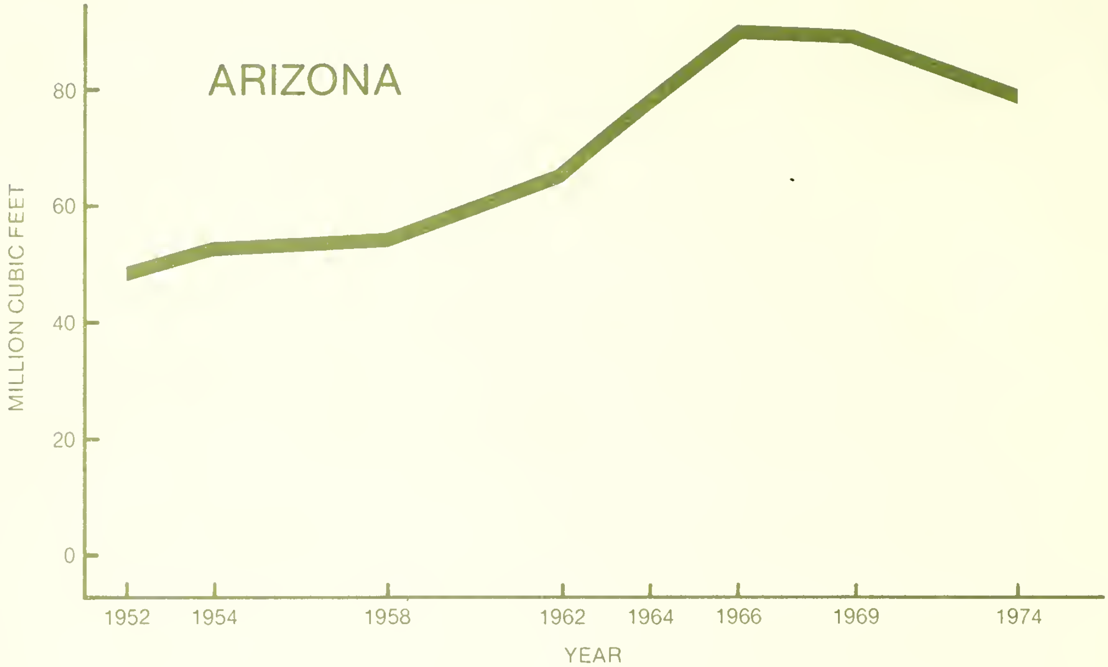

Figure 1.--Roundwood harvest, 1952-1974. Plotted volumes through 1969 are from Setzer (1971).

Table 1.--*Roundwood harvest from Arizona timberlands by species and product, 1974*

Product	True firs	Engelmann spruce	Ponderosa pine	Douglas-fir	Aspen	Other species[1]	All species: Volume	All species: Percent
	Thousand cubic feet							
Saw logs	3,751	919	48,652	3,289	--	47	56,658	71.8
Pulpwood	--	762	5,649	1,144	381	--	7,936	10.0
Miscellaneous industrial wood[2]	--	--	317	--	43	6	366	.5
Posts, fuelwood, miscellaneous farm timbers	--	--	286	--	--	13,689	13,975	17.7
Total	3,751	1,681	54,904	4,433	424	13,742	78,935	100.0
Percent of total	4.8	2.1	69.6	5.6	.5	17.4	100.0	

[1]Includes juniper; limber, pinyon, and whitebark pines; hardwoods.
[2]Includes commercial poles, excelsior bolts, and mine timbers.

Table 2.--*Mill receipts of saw logs from Arizona timberlands by species and county of origin, 1974*

County	Species					All species	
	True firs	Engelmann spruce	Ponderosa pine	Douglas-fir	Other softwoods	Volume	Percent
	- - Thousand board feet, International 1/4-inch rule - -						
Apache	9,496	324	57,790	1,659	72	69,341	19.1
Coconino	5,152	1,456	126,139	3,472	--	136,219	37.5
Gila	--	--	14,306	--	--	14,306	3.9
Greenlee	2,828	301	1,471	5,676	212	10,488	2.9
Navajo	6,247	3,808	104,331	9,641	19	124,046	34.1
Pima	318	--	5,411	636	--	6,365	1.8
Yavapai	--	--	2,417	--	--	2,417	.7
Total	24,041	5,889	311,865	21,084	303	363,182	100.0
Percent of total	6.6	1.6	85.9	5.8	.1	100.0	
	- - - - - - Thousand board feet, Scribner - - - - - - -						
Apache	8,478	289	51,598	1,481	64	61,910	19.1
Coconino	4,600	1,300	112,624	3,100	--	121,624	37.5
Gila	--	--	12,773	--	--	12,773	3.9
Greenlee	2,525	269	1,313	5,068	189	9,364	2.9
Navajo	5,578	3,400	93,153	8,608	17	110,756	34.1
Pima	284	--	4,831	568	--	5,683	1.8
Yavapai	--	--	2,158	--	--	2,158	.7
Total	21,465	5,258	278,450	18,825	270	324,268	100.0
Percent of total	6.6	1.6	85.9	5.8	.1	100.0	

Approximately 38 percent of Arizona's saw logs came from Coconino County in 1974. Navajo County produced 34 percent, up from 23 percent in 1969 and 13 percent in 1966. Apache County saw log production was slightly more than 19 percent of the State total, down from 25 percent in 1969.

About 59 percent of the timber produced in 1974 came from National Forest lands. Nearly all of the remainder came from Indian and other private lands. In 1966 about 75 percent of the timber produced came from National Forest lands with Indian lands supplying most of the balance.

The trend of increasing sawmill residues utilization continued in 1974. Eighty-six percent of the volume of residues produced was used, compared to 54 percent in 1969 (table 3). Coarse residue utilization approached 100 percent, largely because about 12 of Arizona's sawmills have chipping equipment, and the dozen or so smaller mills without chippers have ready fuelwood markets.

Table 3.--*Estimated volume of used and unused residues from sawmills in Arizona, 1974*

Residues	Total 1969	Total 1974	Unused 1969	Unused 1974	Used 1969	Used 1974
	- - - - - - - - -	*Thousand cubic feet*	- - - - - - - - -			
Bark	10,578	7,224	8,025	1,010	2,553	6,214
Coarse[1]	16,475	12,567	2,469	498	14,006	12,069
Fine[2]	17,855	14,153	10,245	3,365	7,610	10,788

[1]Material suitable for chipping, such as slabs, edgings, and trimmings.
[2]Material such as sawdust and shavings.

Residues were used predominantly for pulp chips and fuel, with some bark and fine residues used for livestock bedding and mulch.

Arizona's 64.5 million cubic feet of timber production from growing stock in 1974 represents 1.34 percent of the State's net growing stock volume on commercial forest land. Comparable gross growth is 1.79 percent of net growing stock volume. Figure 2 shows timber production for two selected years, net annual growth, and annual mortality. Estimates of commercial forest land area by site classes, growing stock volume, growth, mortality, and salvable dead volumes are for 1970 (Green and Setzer 1974).

The figure 2 comparisons suggest that Arizona timber, under present forest management, is being harvested near the maximum sustainable level.

Volume of products from dead trees was 10.2 million cubic feet, which is about 68.2 percent of annual mortality or about 7.7 percent of the State's total volume of salvable dead trees. Apparently few opportunities remain to increase timber production by capturing new mortality but perhaps additional utilization of existing salvable dead material is possible.

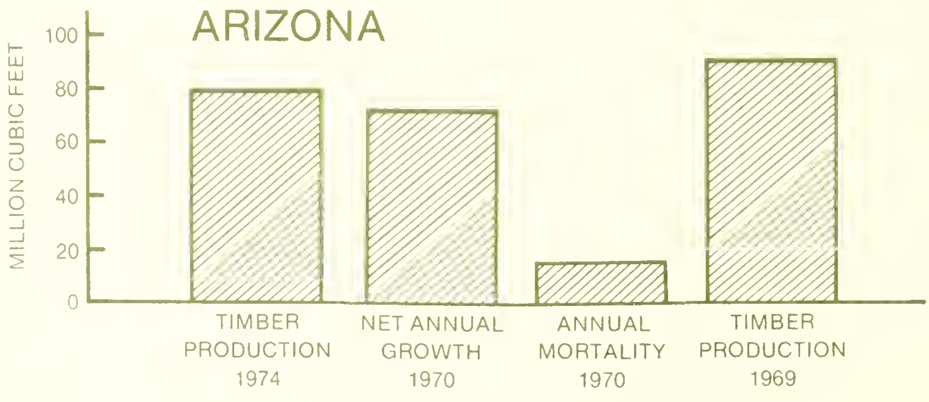

Figure 2.--Relationship of timber production for 1974 and 1969, net annual growth, and annual mortality.

Average stocking of Arizona's commercial forest land including all classes of timber is 1,435 cubic feet per acre. Because partial cutting is commonly used in the State, the average cut per acre is assumed to be about 600 cubic feet (3,000 board feet). Cutting at this rate would have required about 132,000 acres to yield the 1974 harvest volume.

There appears to be a substantial opportunity for increasing annual timber production in Arizona if the potential productivity of the commercial forest land can be reached and maintained. An estimate of potential annual productivity for Arizona is 177.5 million cubic feet. It was calculated by multiplying the midpoint cubic foot value of each site class by its associated area (Green and Setzer 1974) and summing the products.

Expressed in terms of production per acre of commercial forest land, the harvest volume in 1974 was calculated as 21.7 cubic feet, or 91.52 percent of gross growth on commercial forest land. At the full potential level of gross growth, 44.67 cubic feet per acre could be harvested from commercial forest land without cutting more than 91.52 percent of gross growth. This would amount to an increase in harvest of about 84 million cubic feet per year for the State.

ACKNOWLEDGMENT

We appreciate the cooperation of the owners and operators of Arizona's primary wood-using industries in supplying data for this report. Data were collected jointly by the Arizona State Land Department, Forestry Division; State and Private Forestry, Southwestern Region, Forest Service; and the Intermountain Forest and Range Experiment Station.

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Green, Alan W., and Theodore S. Setzer.
1974. The Rocky Mountain timber situation, 1970. USDA For. Serv. Resour. Bull. INT-10, 78 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Setzer, Theodore S.
1971. Estimates of timber products output and plant residues, Arizona, 1969. USDA For. Serv. Res. Note INT-130, 4 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Commercial forest land	Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood under management. Inaccessible areas and areas that cannot be harvested with available equipment are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)
Gross growth	Annual increase in net volume of trees in the absence of cutting and mortality.
Growing-stock trees	Live trees of commercial species meeting specified standards of quality or vigor; excludes cull trees.
Net annual growth	The increase in net volume of a specified size class for a specific year. (Components of net annual growth include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus net volume of trees reaching the size class during the year, minus the net volume of trees that died during the year, minus the net volume of trees that became rough or rotten trees during the year.)
Mill residues	Wood materials from manufacturing plants not utilized for the mill's primary product. (In this report, includes slabs, edgings, trimmings, miscuts, sawdust, and shavings.)
Roundwood products	Logs, bolts, or other round sections cut from trees for industrial or consumer uses. (In this report, includes saw logs, pulpwood, fuelwood, piling, poles, hewn ties, mine timbers, and various other round, split, or hewn products.)
Site class	A classification of forest land in terms of inherent capacity to grow crops of industrial wood.
Timber production	Production of roundwood timber products.

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507 — 25th Street, Ogden, Utah 84401

USDA Forest Service
Research Note INT-231

September 1977

NEW MEXICO TIMBER PRODUCTION AND MILL RESIDUES, 1974

Theodore S. Setzer, Resource Analyst
Michael K. Barrett, Statistical Clerk

ABSTRACT

Roundwood timber production in New Mexico in 1974 was 36 million cubic feet, down substantially from 1969's 47.2 million cubic feet. Saw log production was 27.9 million cubic feet, compared to 39.2 million cubic feet in 1969. Estimated volume of sawmill residues was 21.9 million cubic feet, of which nearly 11 million cubic feet was used, principally for pulp chips.

KEYWORDS: primary wood products, sawtimber, pulpwood, sawmill residues use

Roundwood timber production in New Mexico in 1974 was 36.1 million cubic feet, down 24 percent from 1969, and 29 percent less than the record high of 1966 (fig. 1).

Saw logs, as in past years, were the major timber product in 1974 (table 1). Saw log production in the State was 27.9 million cubic feet (178.7 million board feet).[1] This volume was down 72.7 million board feet from 1969, and 92.8 million board feet from 1966. Production of all other roundwood products combined was 8.2 million cubic feet, nearly the same as in 1969.

Ponderosa pine accounted for more than 63 percent of sawmill log receipts (table 2). Douglas-fir and true firs together made up an additional 31 percent. Other species milled included Engelmann spruce and aspen.

The State's three leading saw log producing counties were, in order, Catron, Rio Arriba, and Otero, together contributing about 70 percent of the total. Sandoval County, the leading county in 1969, recorded a significant 82 percent decrease from its 1969 saw log production.

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[1]International 1/4-inch log rule is used throughout this report for board-foot volume of roundwood, unless otherwise specified.

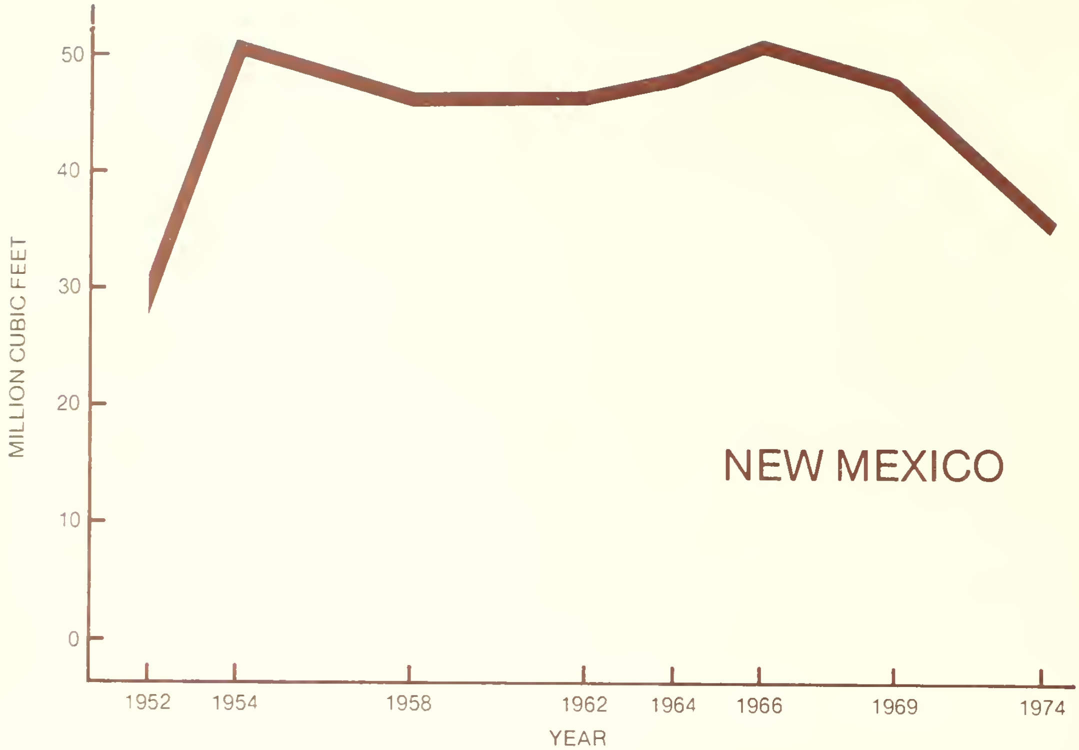

Figure 1.--Roundwood harvest, 1952-1974. Plotted volumes through 1969 are from Setzer (1971).

Table 1.--*Roundwood harvest from New Mexico timberlands by species and product, 1974*

Product	Species: True firs	Engelmann spruce	Ponderosa pine	Douglas-fir	Aspen	Other species[1]	All species: Volume	Percent
	Thousand cubic feet							
Saw logs	2,048	1,256	17,624	6,585	345	13	27,871	77.2
Miscellaneous industrial wood[2]	--	--	531	--	67	1	599	1.7
Posts, fuelwood, miscellaneous farm timbers	--	--	621	--	--	6,980	7,601	21.1
Total	2,048	1,256	18,776	6,585	412	6,994	36,071	100.0
Percent of total	5.6	3.5	52.1	18.3	1.1	19.4	100.0	

[1]Includes juniper and pinyon pine.
[2]Includes commercial poles, house logs, and mine timbers.

Table 2.--*Mill receipts of saw logs from New Mexico timberlands by species and county of origin, 1974*

County	Species						All species	
	True firs	Engelmann spruce	Ponderosa pine	Douglas-fir	Other softwoods	Aspen	Volume	Percent
	Thousand board feet, International 1/4-inch rule							
Catron	962	287	43,913	4,318	56	--	49,536	27.7
Colfax	26	1,142	8,050	4,046	--	--	13,264	7.4
McKinley	580	--	2,318	--	--	--	2,898	1.6
Mora	1,018	223	2,007	1,216	--	--	4,464	2.5
Otero	4,489	24	17,602	12,772	--	--	34,887	19.5
Rio Arriba	5,493	4,357	21,516	7,925	27	2,207	41,525	23.3
Sandoval	--	--	6,068	4,695	--	--	10,763	6.0
San Miguel	524	1,330	1,440	150	--	--	3,444	1.9
Santa Fe	21	--	548	27	--	--	596	.4
Sierra	--	--	776	--	--	--	776	.5
Socorro	--	--	1,128	282	--	--	1,410	.8
Taos	11	692	2,485	2,204	--	8	5,400	3.0
Valencia	--	--	5,120	4,571	--	--	9,691	5.4
Total	13,124	8,055	112,971	42,206	83	2,215	178,654	100.0
Percent of total	7.4	4.5	63.2	23.6	.1	1.2	100.0	
	Thousand board feet, Scribner							
Catron	853	254	38,924	3,827	50	--	43,908	27.7
Colfax	23	1,012	7,135	3,586	--	--	11,756	7.4
McKinley	514	--	2,055	--	--	--	2,569	1.6
Mora	903	198	1,779	1,078	--	--	3,958	2.5
Otero	3,979	21	15,602	11,321	--	--	30,923	19.5
Rio Arriba	4,869	3,862	19,072	7,025	24	1,956	36,808	23.3
Sandoval	--	--	5,379	4,162	--	--	9,541	6.0
San Miguel	465	1,179	1,276	133	--	--	3,053	1.9
Santa Fe	19	--	486	24	--	--	529	.4
Sierra	--	--	688	--	--	--	688	.5
Socorro	--	--	1,000	250	--	--	1,250	.8
Taos	9	613	2,203	1,954	--	7	4,786	3.0
Valencia	--	--	4,538	4,052	--	--	8,590	5.4
Total	11,634	7,139	100,137	37,412	74	1,963	158,359	100.0
Percent of total	7.4	4.5	63.2	23.6	.1	1.2	100.0	

Table 3.--*Estimated volume of used and unused residues from sawmills in New Mexico*

Residues	Total		Unused		Used	
	1969	1974	1969	1974	1969	1974
	Thousand cubic feet					
Bark	6,173	4,989	6,093	3,264	80	1,725
Coarse[1]	9,681	8,126	3,750	2,543	5,931	5,583
Fine[2]	10,455	8,750	10,413	5,109	42	3,641

[1]Material suitable for chipping such as slabs, edgings, and trimmings.
[2]Material such as sawdust and shavings.

About 61 percent of 1974's timber harvest came from National Forest lands (table 3), the balance came largely from private land. In 1966, only 51 percent came from National Forest lands.

The estimated volume of sawmill residues utilized in 1974 was 10.9 million cubic feet, about 50 percent of the total available (table 3). In 1969, 23 percent of the volume was used. Nearly 70 percent of the coarse residues were used, mainly for pulp chips, but some for fuel.

Timber production from growing stock in New Mexico in 1974 was 28.1 million cubic feet, less than one percent of the net growing stock volume on commercial forest land. Figure 2 shows timber production for two selected years, net annual growth, and annual mortality. Estimates of commercial forest land area, growing stock volume, growth, mortality, and salvable dead volumes are for 1970 (Green and Setzer 1974). Timber production was less than 30 percent of gross growth and less than 50 percent of net growth in 1974. We conclude that New Mexico could increase timber harvesting without exceeding a sustainable level.

Volume of products from dead trees was 7.6 million cubic feet, which is about 16 percent of annual mortality or 2.2 percent of the State's volume of salvable dead trees. Timber production could be increased by capturing more new mortality and by utilizing more of the existing salvable dead trees.

Average stocking of New Mexico's commercial forest land including all classes of timber is 1,282 cubic feet per acre. Because partial cutting is commonly used in the State, the average cut per acre is assumed to be about 500 cubic feet (2,500 board feet). Cutting at this rate would require about 72,000 acres to yield the 1974 harvest volume.

There is an opportunity for increasing annual timber production in New Mexico if the potential productivity of the commercial forest land can be reached and maintained. An estimate of potential annual productivity for New Mexico is 261.9 million cubic feet. It was calculated by multiplying the midpoint cubic foot value of each site class by its associated area (Green and Setzer 1974) and summing the products. Expressed in terms of production per acre of commercial forest land, the harvest volume in 1974 was calculated as 6.44 cubic feet, or 29.6 percent of gross growth on commercial forest land. At the full potential level of gross growth, about 13.8 cubic feet per acre could be harvested on commercial forest land without cutting more than 29.6 percent of gross growth. This would amount to an increase in harvest of more than 41 million cubic feet per year for the State.

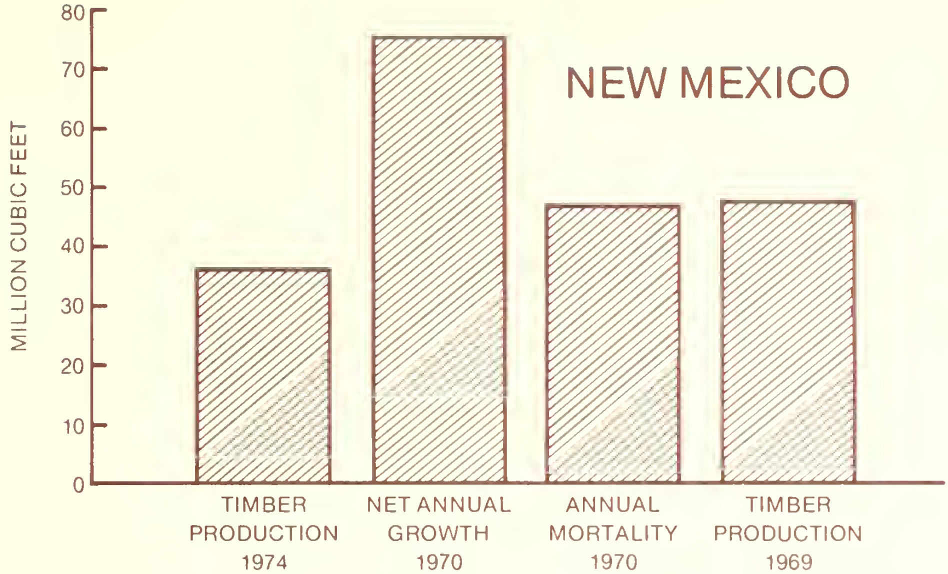

Figure 2.--Relationship of New Mexico timber production for 1974 and 1969, net annual growth, and annual mortality.

ACKNOWLEDGMENT

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GLOSSARY

Commercial forest land	Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood under management. Inaccessible areas and areas that cannot be harvested with available equipment are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)
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Growing-stock trees	Live trees of commercial species meeting specified standards of quality or vigor; excludes cull trees.
Net annual growth	The increase in net volume of a specified size class for a specific year. (Components of net annual growth include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus net volume of trees reaching the size class during the year, minus the net volume of trees that died during the year, minus the net volume of trees that became rough or rotten trees during the year.)
Mill residues	Wood materials from manufacturing plants not utilized for the mill's primary product. (In this report, includes slabs, edgings, trimmings, miscuts, sawdust, and shavings.)
Roundwood products	Logs, bolts, or other round sections cut from trees for industrial or consumer uses. (In this report, includes saw logs, pulpwood, fuelwood, piling, poles, hewn ties, mine timbers, and various other round, split, or hewn products.)
Site class	A classification of forest land in terms of inherent capacity to grow crops of industrial wood.
Timber production	Production of roundwood timber products.

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USDA Forest Service
Research Note INT-232

September 1977

COLORADO TIMBER PRODUCTION AND MILL RESIDUES, 1974

Theodore S. Setzer, Resource Analyst
Dorothy G. Shupe, Statistical Assistant

ABSTRACT

Colorado roundwood timber production in 1974 was 47.3 million cubic feet, down about 1 million cubic feet from the 1969 estimate, and 3.6 million cubic feet from 1966. Saw log and veneer log production combined totaled 40.2 million cubic feet, almost the same as in 1969. No round pulpwood production was reported in 1974. The estimated volume of mill residues from the lumber and veneer and plywood industries was 22 million cubic feet. The volume of residues used, mainly as pulp chips and fuel, was 18.5 million cubic feet.

KEYWORDS: primary wood products, sawtimber, pulpwood, mill residues use

In 1974, Colorado's timber harvest was estimated to be 47.3 million cubic feet. This volume was about 2 percent less than the 1969 harvest and 7 percent less than the record high production of 1966 (fig. 1).

Combined saw log and veneer log production in 1974 was 40.2 million cubic feet (table 1). This volume is comparable to 1969 production of 40.3 million cubic feet, although the proportion of the two products was somewhat different. Veneer log volume was higher, and saw log volume lower, in 1969. No round pulpwood production was reported in 1974. All other roundwood products combined totaled 7.1 million cubic feet, slightly less than in 1969.

Engelmann spruce accounted for 43 percent of mill receipts of saw logs (tables 2 and 3) and lodgepole pine, ponderosa pine, and Douglas-fir combined accounted for an additional 48 percent. Aspen volume increased substantially from 1969.

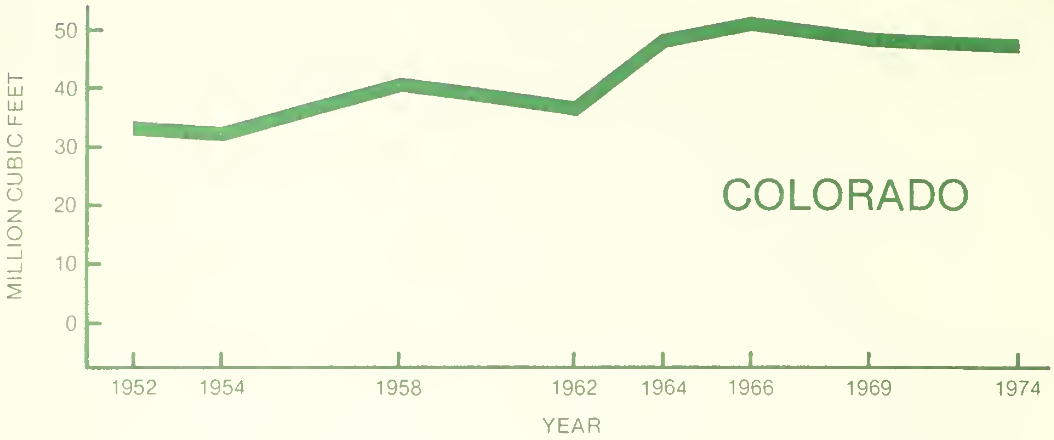

Figure 1.--Roundwood harvest, 1952-1974. Plotted volumes through 1969 are from Setzer (1971)

Table 1.--*Roundwood harvest from Colorado timberlands by species and product, 1974*

Product	Species						All species	
	True firs	Engelmann spruce	Lodgepole pine	Ponderosa pine	Douglas-fir	Aspen, cottonwood[1]	Volume	Percent
	Thousand cubic feet							
Saw logs and veneer logs	2,650	17,440	7,371	7,192	4,705	863	40,221	85.1
Miscellaneous industrial wood[2]	1	887	1,117	902	3	1,376	4,286	9.0
Posts, fuelwood, miscellaneous farm timbers	([3])	34	1,317	501	2	923	2,777	5.9
Total	2,651	18,361	9,805	8,595	4,710	3,162	47,284	100.0
Percent of total	5.6	38.8	20.7	18.2	10.0	6.7	100.0	

[1]Includes juniper.
[2]Includes commercial poles, excelsior bolts, house logs, match stock, and mine timbers.
[3]Less than 0.5 thousand cubic feet.

Table 2.--*Mill receipts of saw logs from Colorado timberlands by species and county of origin, 1974*

County	Species						All species	
	True firs	Engelmann spruce	Lodgepole pine	Ponderosa pine	Douglas-fir	Aspen, cottonwood	Volume	Percent
	Thousand board feet, International 1/4-inch rule							
Alamosa	--	--	--	--	--	445	445	0.2
Archuleta	4,324	5,612	--	12,272	4,619	1,011	27,838	11.6
Boulder	--	--	7	93	--	--	100	([1])
Conejos	--	5,916	--	222	589	--	6,727	2.8
Custer	74	148	--	964	1,483	--	2,669	1.1
Delta	--	1,112	--	148	222	--	1,482	.6
Dolores	--	11,084	--	903	556	1,668	14,211	5.9
Douglas	--	--	--	216	22	--	238	.1
Eagle	--	2,488	3,359	--	--	--	5,847	2.4
Elbert	--	--	--	297	--	--	297	.1
El Paso	--	--	--	319	--	--	319	.1
Garfield	111	2,300	--	--	74	--	2,485	1.0
Grand	479	5,176	14,958	--	--	--	20,613	8.6
Gunnison	15	13,175	252	--	37	445	13,924	5.8
Huerfano	44	--	--	1,134	1,275	--	2,453	1.0
Jackson	341	3,996	18,943	--	--	--	23,280	9.7
La Plata	7,414	7,414	--	15,087	14,828	--	44,743	18.7
Larimer	--	222	3,835	1,787	1	--	5,845	2.4
Las Animas	--	--	--	741	371	--	1,112	.5
Logan	--	--	--	37	--	--	37	([1])
Mesa	--	5,190	--	692	--	--	5,882	2.5
Mineral	2,401	10,770	--	--	130	--	13,301	5.6
Moffat	--	--	30	--	--	148	178	.1
Montezuma	--	2,780	--	185	185	1,520	4,670	2.0
Montrose	--	--	--	2,298	741	--	3,039	1.3
Park	--	--	--	282	--	--	282	.1
Pitkin	--	279	92	--	--	--	371	.2
Pueblo	1	--	--	24	4	168	197	.1
Rio Blanco	--	193	74	--	148	--	415	.2
Rio Grande	630	10,645	--	311	574	--	12,160	5.1
Routt	--	5,995	5,700	--	--	--	11,695	4.9
Saguache	3	8,139	--	357	4,297	--	12,796	5.3
Teller	--	--	--	52	--	--	52	([1])
Total	15,837	102,634	47,250	38,421	30,156	5,405	239,703	100.0

[1]Less than 0.05 percent.

La Plata County again led the State in saw log production with 44.7 million board feet (table 2),[1] followed by Archuleta County with 27.8 million board feet, and Jackson County with 23.3 million board feet. Forty percent of the saw log volume came from these three counties.

National Forests provided 90 percent of the volume of roundwood products in 1974, about the same as in 1966. Nearly all of the remainder came from private lands.

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[1]International 1/4-inch log rule is in the text of this report for board-foot volumes of roundwood unless otherwise specified.

Table 3.--*Mill receipts of saw logs from Colorado timberlands by species and county of origin, 1974*

County	Species						All species	
	True firs	Engelmann spruce	Lodgepole pine	Ponderosa pine	Douglas-fir	Aspen, cottonwood	Volume	Percent
	Thousand board feet, Scribner							
Alamosa	--	--	--	--	--	397	397	0.2
Archuleta	3,861	5,011	--	10,957	4,124	903	24,856	11.6
Boulder	--	--	7	83	--	--	90	([1])
Conejos	--	5,282	--	199	526	--	6,007	2.8
Custer	66	132	--	861	1,324	--	2,383	1.1
Delta	--	993	--	132	199	--	1,324	.6
Dolores	--	9,896	--	806	496	1,489	12,687	5.9
Douglas	--	--	--	193	20	--	213	.1
Eagle	--	2,222	2,999	--	--	--	5,221	2.4
Elbert	--	--	--	265	--	--	265	.1
El Paso	--	--	--	285	--	--	285	.1
Garfield	99	2,053	--	--	66	--	2,218	1.0
Grand	428	4,622	13,356	--	--	--	18,406	8.6
Gunnison	13	11,763	225	--	33	397	12,431	5.8
Huerfano	40	--	--	1,013	1,139	--	2,192	1.0
Jackson	305	3,568	16,913	--	--	--	20,786	9.7
La Plata	6,620	6,620	--	13,471	13,239	--	39,950	18.7
Larimer	--	199	3,424	1,595	1	--	5,219	2.4
Las Animas	--	--	--	662	331	--	993	.5
Logan	--	--	--	33	--	--	33	([1])
Mesa	--	4,634	--	618	--	--	5,252	2.5
Mineral	2,143	9,616	--	--	117	--	11,876	5.6
Moffat	--	--	26	--	--	132	158	.1
Montezuma	--	2,482	--	165	165	1,357	4,169	2.0
Montrose	--	--	--	2,052	662	--	2,714	1.3
Park	--	--	--	252	--	--	252	.1
Pitkin	--	249	82	--	--	--	331	.2
Pueblo	1	--	--	21	4	150	176	.1
Rio Blanco	--	172	66	--	132	--	370	.2
Rio Grande	563	9,504	--	278	512	--	10,857	5.1
Routt	--	5,353	5,089	--	--	--	10,442	4.9
Saguache	3	7,267	--	319	3,837	--	11,426	5.3
Teller	--	--	--	46	--	--	46	([1])
Total	14,142	91,638	42,187	34,306	26,927	4,825	214,025	100.0

[1]Less than 0.05 percent.

Table 4.--*Estimated volume of used and unused residues from mills in Colorado, 1974*

Residues	Total		Unused		Used	
	1969	1974	1969	1974	1969	1974
	Thousand cubic feet					
Bark	6,431	5,345	6,401	3,853	30	1,492
Coarse[1]	10,503	9,003	6,012	2,070	4,491	6,933
Fine[2]	9,395	8,401	6,518	4,285	2,877	4,116

[1]Material suitable for chipping, such as slabs, edgings, and trimmings.
[2]Material such as sawdust and shavings.

Utilization of mill residues has increased substantially since 1966 (table 4). Sixty-three percent of the combined volume of coarse and fine residues from the lumber and veneer and plywood industries was utilized in 1974, compared to 11 percent in 1966. The principal uses were for pulp chips, fuel, and livestock bedding.

Timber production from growing stock was 43.4 million cubic feet. This was 0.35 percent of the State's net growing stock volume on commercial forest land. Comparable gross growth was 2.02 percent of net growing stock volume. Figure 2 shows timber production for two selected years, net annual growth, and annual mortality. Estimates of commercial forest land area by site classes, growing stock volume, growth, mortality, and salvable dead volumes are for 1970 (Green and Setzer 1974).

The figure 2 comparisons suggest that with present forest management Colorado timber production could be increased substantially without exceeding a sustainable level.

Volume of products from dead trees was 3.7 million cubic feet, which is 4 percent of annual mortality and about 0.3 percent of the State's estimated total volume of salvable dead trees. There appear to be opportunities to increase production by capturing new mortality and utilizing greater quantities of existing salvable dead material.

Average stocking of the State's commercial forest land is 1,653 cubic feet per acre. If all of this volume is assumed to be merchantable, 1974's timber production would have required cutting on about 28,600 acres, or a fraction of 1 percent of the commercial forest acreage.

Because of the shift to partial cutting in recent years in Colorado, the area cut over annually is considerably larger. Assuming a harvest of about 900 cubic feet per acre (5,400 board feet) with partial cutting, the area necessary to produce the 1974 harvest volume would have been about 53,000 acres, still less than 1 percent of the commercial forest land in the State.

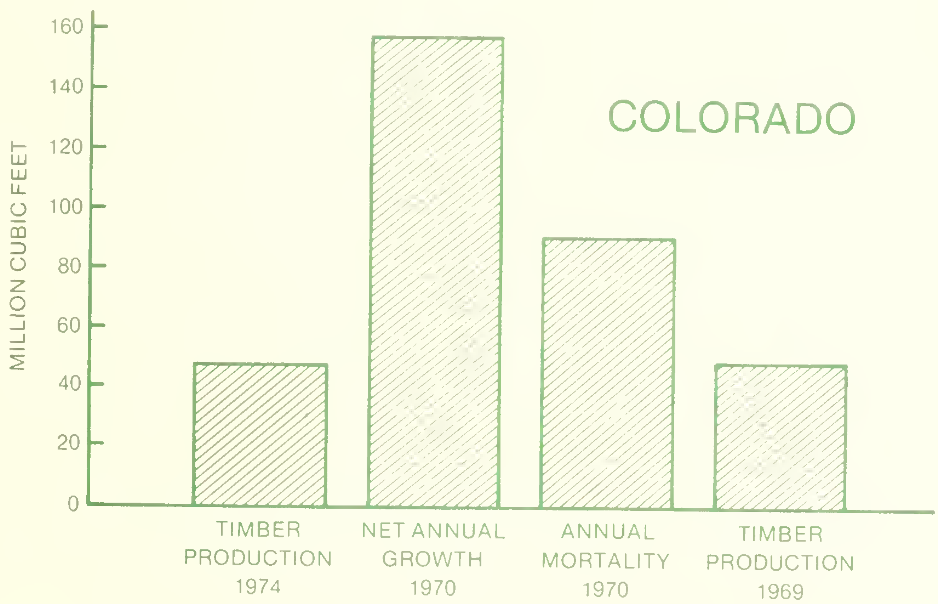

Figure 2.--Relationship of timber production for 1974 and 1969, net annual growth, and annual mortality.

The 1974 timber production expressed on a per acre of commercial forest land basis was 5.23 cubic feet, or 19.09 percent of gross growth per acre. If potential productivity could be achieved on the State's commercial forest land, average gross growth per acre would increase from the current 27.40 cubic feet to 43.34 cubic feet. An estimate of potential annual productivity for Colorado is 391.8 million cubic feet. It was calculated by multiplying the midpoint cubic foot value of each site class by its associated area (Green and Setzer 1974) and summing the products. Colorado forest land producing at its potential could yield more timber on the same number of acres, or provide the same yield from fewer acres.

ACKNOWLEDGMENT

We appreciate the cooperation of the owners and operators of Colorado's primary wood-using industries in supplying data for this report. Data were collected jointly by the Colorado State Forest Service and the Intermountain Forest and Range Experiment Station.

PUBLICATIONS CITED

Green, Alan W., and Theodore S. Setzer.
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GLOSSARY

Commercial forest land	Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood under management. Inaccessible areas and areas that cannot be harvested with available equipment are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)
Gross growth	Annual increase in net volume of trees in the absence of cutting and mortality.
Growing-stock trees	Live trees of commercial species meeting specified standards of quality or vigor; excludes cull trees.
Net annual growth	The increase in net volume of a specified size class for a specific year. (Components of net annual growth include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus net volume of trees reaching the size class during the year, minus the net volume of trees that died during the year, minus the net volume of trees that became rough or rotten trees during the year.)
Mill residues	Wood materials from manufacturing plants not utilized for the mill's primary product. (In this report, includes slabs, edgings, trimmings, miscuts, sawdust, shavings, and veneer cores and clippings.)
Roundwood products	Logs, bolts, or other round sections cut from trees for industrial or consumer uses. (Includes saw logs, veneer logs and bolts, pulpwood, fuelwood, piling, poles, hewn ties, mine timbers, and various other round, split, or hewn products.)
Site class	A classification of forest land in terms of inherent capacity to grow crops of industrial wood.
Timber production	Production of roundwood timber products.

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USDA Forest Service
Research Note INT-233

September 1977

WESTERN SOUTH DAKOTA TIMBER PRODUCTION AND MILL RESIDUES, 1974

Theodore S. Setzer, Resource Analyst
Michael K. Barrett, Statistical Clerk

ABSTRACT

Roundwood timber production in South Dakota was 18 million cubic feet in 1974, up almost 20 percent from 1969's 15 million cubic feet. Saw log production was 12 million cubic feet compared to 7.4 million cubic feet in 1969. The estimated volume of residues from the sawmills was 7.7 million cubic feet, of which 3.8 million cubic feet was used, principally for pulp chips and fuel.

KEYWORDS: primary wood products, sawtimber, pulpwood, sawmill residues use

Western South Dakota's (west of the 103d meridian) 18 million cubic feet of timber production was at a record high level in 1974 (fig. 1), especially considering that the volume would be even larger if it included roundwood traditionally harvested in the State and processed in neighboring Wyoming plants.

In 1966, 23 percent of western South Dakota's total saw log production was "exported" to Wyoming for processing. It is reasonable to assume that a similar proportion of 1974 saw log production was likewise processed in Wyoming. Because Wyoming was not included in the 1974 timber production study, no 1974 "export" data are available.

Saw log production increased to 76.7 million board feet[1] in 1974 and accounted for two-thirds of the total roundwood harvest (table 1). Saw log volume in 1969 was 47.1 million board feet. Round pulpwood production dropped to 3.8 million cubic feet from 5.3 million cubic feet in 1969, thus ending the upward trend evident since 1958. All other roundwood products combined totaled 2.2 million cubic feet, slightly lower than in 1969.

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[1]International 1/4-inch log rule is used throughout this report for board-foot volume of roundwood unless otherwise specified.

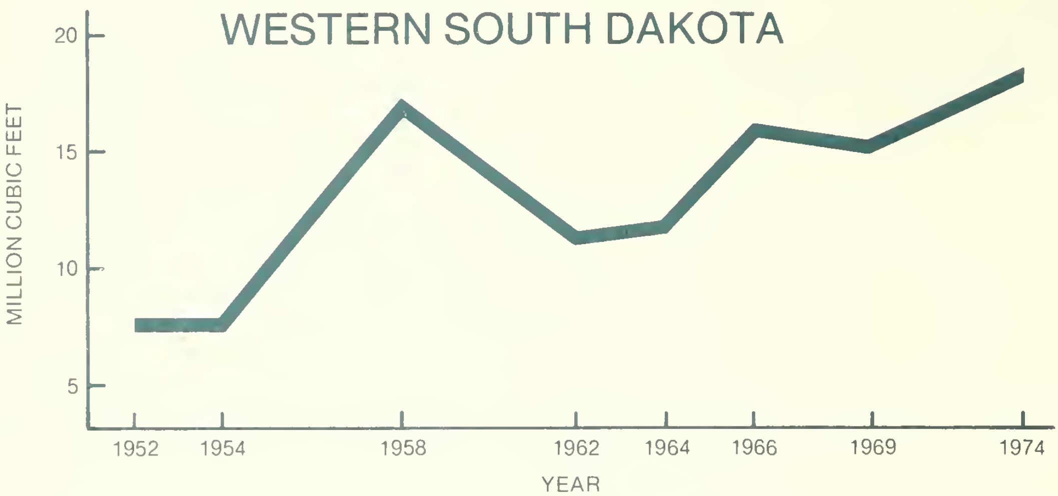

Figure 1.--Roundwood production, 1952-1974. Plotted volumes through 1969 are from Setzer (1971).

The entire saw log production in 1974 was reported from five counties (table 2). Among these was Harding County, which had no reported saw log production in previous studies dating back to 1952.

Three-fourths of western South Dakota timber came from National Forest lands, about 9 percent less than in 1966. Nearly all the remainder came from private lands.

One-half of the volume of sawmill residues was utilized in 1974 compared to 35 percent in 1969. Sixty-four percent of the volume of coarse and fine residues combined was utilized, up from 45 percent in 1969 and continuing the increasing trend of mill residues utilization (table 3). Coarse residues use approached 90 percent, relating to chipping equipment installed in all the larger mills and ready fuelwood markets available to the smaller ones.

Table 1.--*Roundwood harvest from western South Dakota timberlands by species and product, 1974*

Product	Species		All species	
	Ponderosa pine	White spruce	Volume	Percent
	Thousand cubic feet			
Saw logs	11,963	1	11,964	66.6
Pulpwood	3,783	--	3,783	21.1
Commercial poles	515	--	515	2.9
Posts, fuelwood, miscellaneous farm timbers	1,689	--	1,689	9.4
Total	17,950	1	17,951	100.0
Percent of total	100.0	([1])	100.0	

[1]Less than 0.05 percent.

Table 2.--*Mill receipts of saw logs from western South Dakota timberlands by species and county of origin, 1974*

County	Species: Ponderosa pine	Species: White spruce	All species: Volume	All species: Percent
	- Thousand board feet, International 1/4-inch rule -			
Custer	13,513	--	13,513	17.6
Harding	412	--	412	.5
Lawrence	38,903	3	38,906	50.7
Meade	3,810	--	3,810	5.0
Pennington	20,047	--	20,047	26.2
Total	76,685	3	76,688	100.0
	- - - - - Thousand board feet, Scribner - - - - -			
Custer	12,065	--	12,065	17.6
Harding	368	--	368	.5
Lawrence	34,735	3	34,738	50.7
Meade	3,402	--	3,402	5.0
Pennington	17,899	--	17,899	26.2
Total	68,469	3	68,472	100.0

Table 3.--*Estimated volume of used and unused residues from sawmills in western South Dakota, 1974*

Residues	Total		Unused		Used	
	1969	1974	1969	1974	1969	1974
	- - - - - - - - - - Thousand cubic feet - - - - - - - - - - - - - -					
Bark	1,176	1,955	1,168	1,801	8	154
Coarse[1]	1,835	3,184	581	416	1,254	2,768
Fine[2]	1,984	2,602	1,510	1,677	474	925

[1]Material suitable for chipping, such as slabs, edgings, and trimmings.

[2]Material such as sawdust and shavings.

Timber production from growing stock in western South Dakota in 1974 was 17.7 million cubic feet, which was about 1.8 percent of the net growing stock volume on commercial forest land. Figure 2 shows timber production for two selected years, net annual growth, and annual mortality. Estimates of commercial forest land area by site classes, growing stock volume, growth, mortality, and salvable dead volumes are for 1970 (Green and Setzer 1974).

Production in 1974 was 62 percent of gross growth and 65 percent of net annual growth. It appears that western South Dakota commercial forest land could support some increase in the harvest level.

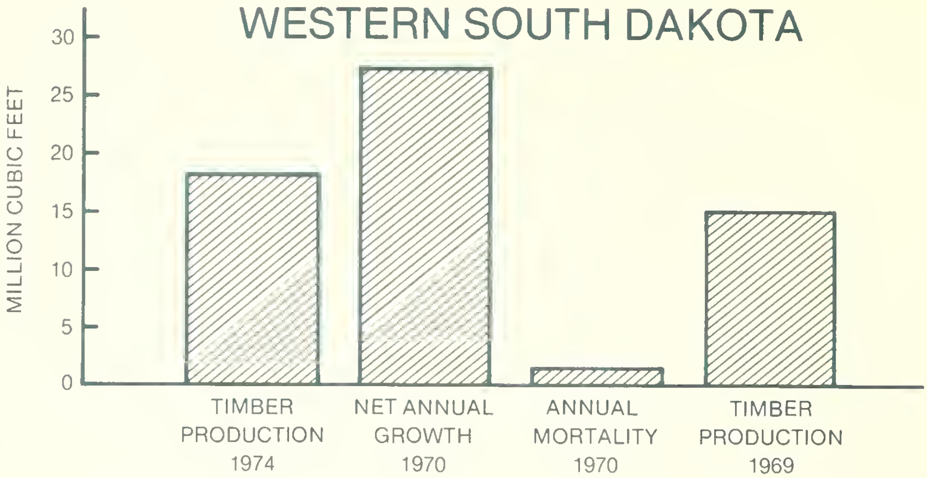

Figure 2.--Relationship of timber production for 1974 and 1969, net annual growth, and annual mortality.

Volume of products from dead trees was 114,000 cubic feet, which is about 9 percent of annual mortality, or 0.2 percent of the volume of salvable dead trees. There appear to be opportunities to increase timber production by capturing new mortality and utilizing greater quantities of existing salvable dead trees.

Average stocking of western South Dakota's commercial forest land is 846 cubic feet per acre. Assuming a harvest of 600 cubic feet per acre (3,100 board feet) with partial cutting, the area necessary to yield the 1974 timber volume would have been at least 30,000 acres or about 2.4 percent of the commercial forest land.

There is opportunity for increasing annual timber production in western South Dakota if the potential productivity of the commercial forest land can be reached and maintained. An estimate of potential annual productivity for South Dakota is 44.6 million cubic feet. It was calculated by multiplying the midpoint cubic foot value of each site class by its associated area (Green and Setzer 1974) and summing the products.

Expressed in terms of production per acre of commercial forest land, the volume of timber produced in 1974 was calculated as 14.32 cubic feet, or 63.25 percent of gross growth on commercial forest land. At the full potential productivity level, 22.48 cubic feet per acre could be harvested on commercial forest land without cutting more than 63.25 percent of gross growth. This increase would amount to more than 10 million cubic feet per year for western South Dakota.

ACKNOWLEDGMENT

We appreciate the cooperation of the owners and operators of South Dakota's primary wood-using industries in supplying data for this report. Data were collected jointly by the Division of Forestry, South Dakota Department of Game, Fish, and Parks and the Intermountain Forest and Range Experiment Station.

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GLOSSARY

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Gross growth	Annual increase in net volume of trees in the absence of cutting and mortality.
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Mill residues	Wood materials from manufacturing plants not utilized for the mill's primary product. (In this report, includes slabs, edgings, trimmings, miscuts, sawdust, and shavings.)
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USDA Forest Service
Research Note INT-234

September 1977

UTAH TIMBER PRODUCTION AND MILL RESIDUES, 1974

Theodore S. Setzer, Resource Analyst
Terrence S. Throssell, Mathematician

ABSTRACT

In 1974 Utah's forests produced 12.2 million cubic feet of roundwood, about 5 percent less than in 1969. Saw log production was 10.9 million cubic feet. The estimated volume of sawmill residues was 7.8 million cubic feet, of which 2.3 million cubic feet was used.

KEYWORDS: primary wood products, sawtimber, pulpwood, sawmill residues use

Roundwood timber production in 1974 from Utah's forests was 12.2 million cubic feet, 612,000 cubic feet less than in 1969, and 1.8 million cubic feet less than in 1966 (fig. 1). As in years past, saw logs were the dominant product, accounting for nearly 90 percent of the total roundwood harvest (table 1). Saw log production of nearly 70 million board feet[1] was about 5 percent lower than in 1969 and 10 percent below the 1966 estimate. Production of all other roundwood products combined was 1.3 million cubic feet, down 87,000 cubic feet from 1969.

Three main species or species groups (ponderosa pine, lodgepole pine, and Engelmann spruce) accounted for nearly 87 percent of the State's 1974 sawmill log receipts (table 2). Ponderosa pine volume was down 28 percent from 1969, Engelmann spruce volume up 53 percent, and lodgepole pine volume up 47 percent. Aspen and cottonwood volume combined was 1.2 million cubic feet.

Saw log production came from 22 counties; however, three counties (Uintah, Garfield, and Kane) provided nearly 50 percent of the total. Uintah County production increased more than 400 percent since 1969 while production from San Juan and Duchesne Counties decreased.

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[1] International 1/4-inch log rule is used throughout this report for board-foot volume of roundwood except as reported in table 2, lower.

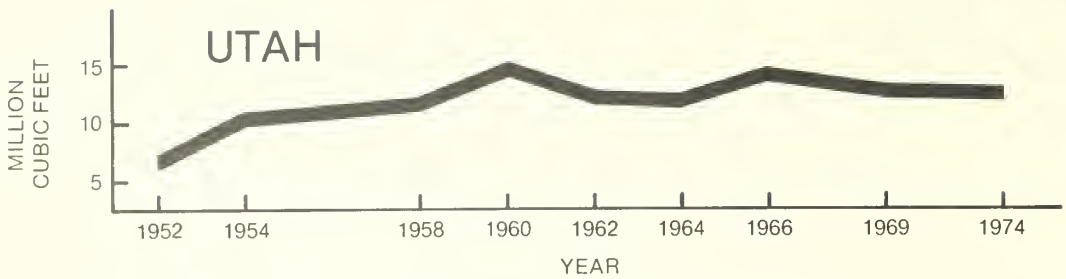

Figure 1.--*Roundwood harvest, 1952-1974. Plotted volumes through 1969 are from Setzer (1971).*

More than 85 percent of timber harvested came from National Forest lands. In 1966, 90 percent came from National Forests.

Thirty percent of the volume of sawmill residues was utilized in 1974 (table 3). Very few mills in the State have chipping equipment; consequently, use of coarse residues for pulp chips is not yet significant. Livestock bedding and fuel are still the major uses of residues.

Utah's 11.3 million cubic feet of timber production from growing stock in 1974 represents 0.24 percent of the State's net growing stock volume on commercial forest land. Comparable gross growth was 2.18 percent of net growing stock volume. Figure 2 shows timber production for two selected years, net annual growth, and annual mortality. Estimates of commercial forest land area by site classes, growing stock volume, growth, mortality, and salvable dead volumes are for 1970 (Green and Setzer, 1974). It seems reasonable to conclude that present forest management could easily support substantially greater timber production in Utah.

Volume of products from dead trees was 756,000 cubic feet, which is only 1.1 percent of annual mortality or about 0.2 percent of the State's total volume of salvable dead trees. There appears to be ample opportunity to increase production by capturing new mortality and utilizing more existing salvable dead trees.

Table 1.--*Roundwood harvest from Utah timberlands by species and product, 1974*

Product	Species							All species	
	True firs	Engelmann spruce	Lodgepole pine	Ponderosa pine	Douglas-fir	Aspen, cottonwood[1]	Other species[2]	Volume	Percent
	Thousand cubic feet								
Saw logs	317	2,603	2,825	4,034	943	192	--	10,914	89.5
Miscellaneous industrial wood[3]	1	29	377	4	9	351	--	771	6.3
Posts, fuelwood, miscellaneous farm timbers	--	--	63	--	--	--	446	509	4.2
Total	318	2,632	3,265	4,038	952	543	446	12,194	100.0
Percent of total	2.6	21.6	26.8	33.1	7.8	4.5	3.6	100.0	

[1]Includes a very small volume of other hardwoods.
[2]Includes juniper, limber pine, and pinyon pine.
[3]Includes commercial poles, excelsior bolts, and mine timbers.

Table 2.--*Mill receipts of saw logs from Utah timberlands by species and county of origin, 1974*

County	Species						All species	
	True firs	Engelmann spruce	Lodgepole pine	Ponderosa pine	Douglas-fir	Aspen,[1] cottonwood	Volume	Percent
	- - - - - Thousand board feet, International 1/4-inch rule - - - -							
Beaver	--	174	--	--	--	--	174	.2
Cache	280	1	--	--	1,275	--	1,556	2.2
Carbon	--	224	--	--	--	67	291	.4
Daggett	--	433	1,677	112	1,354	--	3,576	5.1
Duchesne	20	326	2,341	115	28	13	2,843	4.1
Emery	--	--	--	280	--	--	280	.4
Garfield	459	1,336	--	6,937	784	6	9,522	13.6
Grand	--	--	--	5,600	--	--	5,600	8.0
Kane	224	459	--	6,227	347	--	7,257	10.4
Millard	--	--	--	--	--	33	33	.1
Morgan	--	--	--	--	--	12	12	([2])
Piute	--	493	--	--	--	--	493	.7
Rich	476	30	--	--	1,912	--	2,418	3.5
San Juan	--	--	--	5,600	--	--	5,600	8.0
Sanpete	196	319	--	--	--	67	582	.8
Sevier	--	19	--	754	--	28	801	1.1
Summit	358	3,566	2,023	--	314	--	6,261	9.0
Uintah	--	4,380	11,845	--	--	185	16,410	23.5
Utah	--	--	--	--	22	--	22	([2])
Wasatch	22	806	224	--	--	746	1,798	2.6
Wayne	--	4,116	--	230	11	17	4,374	6.3
Weber	--	--	--	--	--	56	56	([2])
Total	2,035	16,682	18,110	25,855	6,047	1,230	69,959	100.0
	- - - - - - - - - - - Thousand board feet, Scribner - - - - - - - - -							
Beaver	--	155	--	--	--	--	155	.2
Cache	250	1	--	--	1,138	--	1,389	2.2
Carbon	--	200	--	--	--	60	260	.4
Daggett	--	387	1,497	100	1,209	--	3,193	5.1
Duchesne	18	291	2,090	103	25	12	2,539	4.1
Emery	--	--	--	250	--	--	250	.4
Garfield	410	1,193	--	6,194	700	5	8,502	13.6
Grand	--	--	--	5,000	--	--	5,000	8.0
Kane	200	410	--	5,560	310	--	6,480	10.4
Millard	--	--	--	--	--	30	30	.1
Morgan	--	--	--	--	--	11	11	([2])
Piute	--	440	--	--	--	--	440	.7
Rich	425	27	--	--	1,707	--	2,159	3.5
San Juan	--	--	--	5,000	--	--	5,000	8.0
Sanpete	175	285	--	--	--	60	520	.8
Sevier	--	17	--	673	--	25	715	1.1
Summit	319	3,184	1,806	--	280	--	5,589	9.0
Uintah	--	3,911	10,576	--	--	165	14,652	23.5
Utah	--	--	--	--	20	--	20	([2])
Wasatch	20	720	200	--	--	666	1,606	2.6
Wayne	--	3,675	--	205	10	15	3,905	6.3
Weber	--	--	--	--	--	50	50	([2])
Total	1,817	14,896	16,169	23,085	5,399	1,099	62,465	100.0

[1]Includes small volumes of other hardwoods and juniper.
[2]Less than 0.05 percent.

Table 3.--*Estimated volume of used and unused residues from sawmills in Utah, 1974*

Residues	Total 1969	Total 1974	Unused 1969	Unused 1974	Used 1969	Used 1974
	Thousand cubic feet					
Bark	1,099	1,818	960	1,547	139	271
Coarse[1]	2,784	2,857	2,251	2,179	533	678
Fine[2]	3,000	3,086	2,083	1,715	917	1,371

[1]Material suitable for chipping such as slabs, edgings, and trimmings.
[2]Material such as sawdust and shavings.

Average stocking of the State's commercial forest land is 1,491 cubic feet per acre. If all of this volume is assumed to be of merchantable size, 1974's timber harvest would have required cutting on about 8,200 acres. In recent years, however, there has been a significant shift to partial cutting. Assuming a harvest of about 800 cubic feet per acre (4,000 board feet) with partial cutting, the area necessary to yield 1974 production would have been about 15,200 acres. This area is less than 1 percent of the commercial forest land in Utah.

There is an opportunity to increase annual timber production in Utah if the potential productivity of the commercial forest land can be reached and maintained. An estimate of potential annual productivity for Utah is 143 million cubic feet. It was calculated by multiplying the midpoint cubic foot value of each site class by its associated area (Green and Setzer 1974) and summing the products. Expressed in terms of production per acre of commercial forest land, the volume of production in 1974 was calculated as 3.37 cubic feet, or 11.85 percent of gross growth on commercial forest land. At the full potential productivity level, some 4.7 cubic feet per acre could be harvested on commercial forest land without cutting more than 11.85 percent of gross growth. This would amount to an increase in harvest of about 4.8 million cubic feet per year for the State.

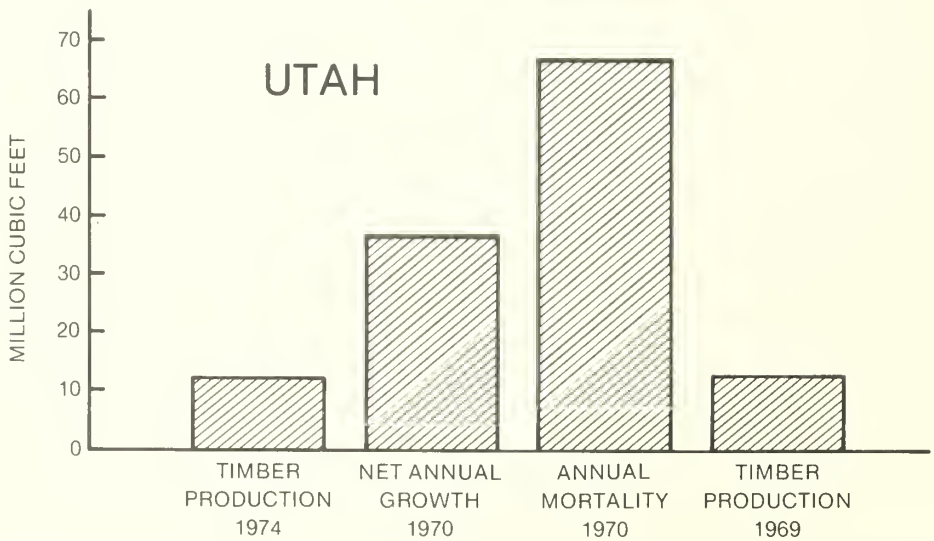

Figure 2.--Relationship of timber production for 1974 and 1969, net annual growth, and annual mortality

ACKNOWLEDGMENT

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1971. Estimates of timber products output and plant residues, Utah and Nevada, 1969. USDA For. Serv. Res. Note INT-135, 4 p. Intermt. For. and Range Exp. Stn. Ogden, Utah.

GLOSSARY

Commercial forest land	Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Areas qualifying as commercial forest land have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood under management. Inaccessible areas and areas that cannot be harvested with available equipment are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)
Gross growth	Annual increase in net volume of trees in the absence of cutting and mortality.
Growing-stock trees	Live trees of commercial species meeting specified standards of quality or vigor; excludes cull trees.
Net annual growth	The increase in net volume of a specified size class for a specific year. (Components of net annual growth include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus net volume of trees reaching the size class during the year, minus the net volume of trees that died during the year, minus the net volume of trees that became rough or rotten trees during the year.)
Mill residues	Wood materials from manufacturing plants not utilized for the mill's primary product. (In this report, includes slabs, edgings, trimmings, miscuts, sawdust, and shavings.)
Roundwood products	Logs, bolts, or other round sections cut from trees for industrial or consumer uses. (In this report, includes saw logs, pulpwood, fuelwood, piling, poles, hewn ties, mine timbers, and various other round, split, or hewn products.)
Site class	A classification of forest land in terms of inherent capacity to grow crops of industrial wood.
Timber production	Production of roundwood timber products.

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October 1977

ALASKAN LIGHTNING STORM CHARACTERISTICS

R. G. Baughman and C. W. Schmid, Jr.[1]

ABSTRACT

The characteristics of 23 cumulus congestus clouds were investigated in interior Alaska during the summer of 1973. Results show Alaskan lightning storms are generally smaller, more isolated, and produce less lightning than western Montana storms. Nine storms produced 123 lightning discharges of which only 8 were cloud-to-ground. Only 1 discharge was recorded with long-continuing current of 40 milliseconds in duration (the type known to start fires in Montana). No lightning-caused fires were reported within many miles of the observed storms. This small sample of Alaskan storms exhibited characteristics that are not conducive to producing large numbers of wildfires.

KEYWORDS: thunderstorms, lightning, fire.

Although lightning is a common cause of wildfire in Alaska, very little is known of the characteristics of individual Alaskan storms and of the accompanying lightning. Therefore, this report is an effort to partially fill this knowledge void. The information reported here was obtained as part of a USDA Forest Service evaluation of a Bureau of Land Management (BLM) program to suppress wildfire by the modification of convective clouds. Although our prime objective was to evaluate the effectiveness of the BLM-sponsored cloud seeding, the supporting data provided valuable information about Alaskan storms, including measurements of individual lightning discharges.

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[1]Respectively, research meteorologist and formerly research physicist, located at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana.

INSTRUMENTATION AND OBSERVATIONS

In agreement with established nomenclature (Uman, 1969), we call any discharge that does not reach earth an intracloud (ic) discharge or cloud-to-cloud discharge, and those that do reach earth cloud-to-ground (cg) discharges. The very high current component of a cg discharge is called a return stroke. Some lightning discharges contain one or more return strokes that terminate in one-thousandth of a second or less, other lightning exhibits continuing current flow for a few hundredths to one- or two-tenths of a second after a return stroke. Lightning discharges with continuing current of 40 or more milliseconds (ms) are called long-continuing current discharges (LCC) (Fuquay and others 1972).

An instrumented, twin-engined, turbocharged, pressurized aircraft served as the data-gathering platform. The airborne recording system consisted of four lightning sensors, a magnetic tape recorder, and supporting electronics. The sensors produced analog signals that were recorded on magnetic tape and later reproduced on a high-speed oscillograph.

The measurements included the electrostatic and radiation fields of lightning. The electrostatic measurements are of two forms: (1) slow changes in time up to hundreds of milliseconds (slow Delta E), and (2) rapid changes in the order of a few milliseconds (fast Delta E). The electrostatic unit consisted of a plate antenna and charge amplifier with a 2-second time constant mounted on the right wingtip and a signal processing unit in the airborne console. In the console, the antenna signal was directly amplified and recorded as slow Delta E and also differentiated on a 5-ms time constant as fast Delta E. The slow and fast Delta E were our primary identifiers of all lightning (Hawe and Fuquay 1969).

This unit detects changes in the electrostatic field due to lightning discharges up to a maximum range of about 20 miles. A VLF antenna mounted on the belly of the aircraft coupled with a receiver tuned to 8 kHz was used to record the VLF radiation field associated with lightning. The output from this unit helped identify cloud-to-ground return strokes (Uman 1969). We also recorded the VHF radiation field at 50 mHz. The VHF unit was used primarily to differentiate between ic and cg lightning. With our system we are able to detect lightning, discriminate between intracloud and cloud-to-ground lightning, count return strokes, and determine the frequency and time duration of continuing current in cg lightning.

In addition to lightning measurements, we observed other cloud phenomena such as temperature and height of cloud bases, height of cloud tops, occurrence of glaciation, and general weather conditions. In accordance with our primary objectives, we focused attention on potential storms in the form of cumulus congestus clouds and, except in one case, avoided ongoing mature storms. As a result, our observations included some clouds that on occasion did not exhibit electric fields or produce lightning. When lightning did occur, we were able to continuously observe the total lightning activity of all storms. Storm observations ranged from near McGrath in the southwest part of interior Alaska, east to the Canadian border, and as far north as the Chandalar River on the south slope of the Brooks Range (67° N lat.). Some 23 clouds were investigated, including 10 clouds seeded with silver iodide; however, unless otherwise noted, the data reported here are from unseeded clouds.

RESULTS

Our results show Alaskan lightning storms to be smaller physically and electrically and more isolated than western Montana storms (for information on Montana storms, see Fuquay 1967). The relative isolation of Alaskan storms was reflected in the ease of maneuvering the aircraft to maintain a favorable position of 1 to 3 miles from an individual cloud at elevations of about 18,000 to 20,000 feet m.s.l. for periods of 15 to 45 minutes. Figure 1 is an example of an isolated lightning storm.

Figure 1.--An example of an isolated lightning storm photographed at 1140 Alaskan daylight time, June 29, 48 miles from Fort Yukon on 120° radial. Aircraft at 22,300 feet.

Favorable recording positions were maintained for 20 of the 23 data clouds throughout the entire recording periods. Smooth flying was experienced at observation height at all times. Cloud-top height of the lightning storms ranged from 20,000 to 33,000 feet, with a median of 25,000 feet for seven observations. Top height was estimated visually from our 18,000 to 20,000 foot position, except in the case of the 33,000-foot cloud, which was measured by a BLM fire patrol jet aircraft. Cloud base heights ranged from 3,500 to 7,000 feet, with a median of 6,000 feet for eight observations (including five seeded clouds). Base temperatures ranged from +3° C at 7,000 feet to +15° C at 3,500 feet (uncorrected aircraft thermometer). Cloud diameters observed in five penetrations by seeding aircraft near the time of first lightning ranged from 1.2 to 3.5 nautical miles. Cirrus was always encountered extending out from parent lightning storms while high level cirrus (well above cumulus cloud tops) was often noted (7 out of 9 observation days).

Clouds in an advanced stage of glaciation (transformation of liquid water to ice) that extended above 18,000 feet always had either a very weak electric field or no electric field and did not produce lightning. Figure 2, an example of a towering cumulus reaching 18,000 feet, shows the fibrous outline of glaciation with no lightning. On the other hand, 3 clouds (of the 23 data clouds) extending above 18,000 feet (temperature level of -17° C) with little or no visual glaciation at initial contact also produce no electric fields or lightning. Four other clouds extending above 23,000 feet (-26° to -28° C) with no visual initial glaciation exhibited strong electric field; two produced no lightning while the other two produced only one discharge each.

These observations suggest that potential Alaskan lightning storms can be characterized as cumulus clouds that are not extensively glaciated at 18,000 feet but upon reaching 23,000 feet possesses a dense cauliflower shape with strong electric fields. This agrees with Alaskan weather modification forecasting procedures where the potential for lightning is deemed to exist when cloud tops reach the -28° C temperature level (Cooper and Heikes 1973).

Lightning recordings suggest that Alaskan storms are not overly active. The amount of lightning produced by individual storms varied from a low of 1 discharge to a high of 53 discharges, with a median of 5 discharges for nine unseeded storms. Lightning activity ranged from 1 minute 22 seconds (2 discharges) to 45 minutes 6 seconds (24 discharges), and the rate of lightning varied from 0.11 per minute to a high of 1.5 per minute.

The largest storm we observed in Alaska was a seeded storm that produced 66 discharges during 65 minutes. The nine unseeded storms produced a total of 110 intracloud, 8 cloud-to-ground, and 5 unidentified discharges. The 8 cg discharges made up only 6 percent of the total, whereas in Montana storms about 25 percent of all discharges are cg (Fuquay and Baughman 1969). This also differs from results of other work where it is suggested that the higher the latitude, the higher the proportion of cg lightning (Pierce 1970). Seven of the eight cg discharges produced only one return stroke each, while the remaining discharge produced five return strokes.

Figure 2.--An example of a towering cumulus reaching 18,000 feet that shows the fibrous outlines of glaciation with no lightning (photographed at 1542 Alaskan daylight time on June 15 about 50 miles from Fairbanks on 050° magnetic radial. Aircraft at 17,600 feet.

As a comparison, western Montana cg lightning averaged four return strokes per dis-harge (Fuquay and Baughman 1969). The decrease in the average number of return strokes er discharge with latitude was predicted by Pierce who also stated that a considerable tatistical sample is necessary to establish satisfactory average values for particular eographic locations. The 8 Alaskan cg discharges did not produce the long-continuing urrent observed in Montana fire-setting lightning (Fuquay and others 1972); however, ontinuing current greater than 5 ms and less than 26 ms was recorded. Discharges from he seeded storms also exhibited continuing currents, at least one of which exceeded 0 ms. No lightning-caused fires were reported within many miles of the storms consid-red here. The lack of cg lightning, the tendency to produce only one return stroke per ischarge, and the absence of long-continuing current discharges probably contributes to he production of fewer fires in Alaska than would occur with more severe storms. The requency of recorded lightning is given in table 1.

As a result of our observations, we hypothesize that in some years Alaskan storms re more active electrically during the morning or early afternoon hours than later in he afternoon. This hypothesis is supported by the data given in table 1, where the otal amount of lightning for clouds exhibiting electric fields is arranged according o initial observation time. This is quite different from Montana storms, where the east active storms tend to occur in morning or early afternoon and the more active torms occur later in the day.

Table 1.--*Lightning observations, interior Alaska 1973. (Clouds with electric field)*

First Observations (Alaska daylight time)	Date	Intracloud	Cloud-to-ground	Total[2]
1113[1]	6/29	65	1	66
1143	7/4	23	0	24
1254	7/4	26	2	29
1255	6/29	1	0	1
1318	6/29	52	0	53
1359	7/5	2	0	2
1405	7/2	2	4	6
1528	7/1	3	2	5
1539	7/4	0	0	1
1533	6/30	0	0	0
1600	7/4	0	0	0
1622	6/30	0	0	0
1624	7/1	1	0	2

[1]Largest storm recorded (seeded).
[2]Includes a few discharges not identified as ic or cg.

SUMMARY

The Alaskan storms that we observed during 1973 were quite small and they produced very little cloud-to-ground lightning. The cg lightning averaged about one return stroke per discharge and only one long-continuing current discharge of the known fire-starting type was recorded. Lightning storms of this nature cause very few fires.

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VARIATION IN CHAR DENSITY ON LABORATORY FUELS

Ralph A. Wilson and Merlin L. Brown[1]

ABSTRACT

Residual char from 76 test burns of wood dowels showed unexpectedly wide variation in density. Variation could not be correlated with initial fuel density, burn time, nor incident windspeed.

KEYWORDS: char, char density, combustion products

While supporting a study of the aerodynamics of burning firebrands, the authors made 76 measurements of char density from free-burning wood (pine *Pinus ponderosa* and birch *Betula* spp.) fuels. We observed an unexpectedly wide variation in the density measurements of the residual char and have found no previous report of the effects.

The fuel samples were pine or birch dowels of various diameters (3/8, 1/2, 1 inch diameter by 5 inches long). Initial fuel characteristics were carefully measured. Ignition and burning conditions were held constant (except for windspeed which was set at values between 0 and 15 miles per hour).

The dowels were ignited in an oxy/gas flame with cylindrical symmetry and were burned with axis vertical in a horizontal wind. After a measured burn time the fire was quenched in dry nitrogen (cooled in dry ice). After quenching, densities were determined by direct weight and volume measurements for (1) the total residual material; (2) the unpyrolyzed core; and (3) the residual char. The "char" included all pyrolyzed (mechanically weak) material that would crumble away from the solid core with very little force. In all cases, the char/core surface was well defined: the transition thickness was <<1 mm. Volumes were determined by an Archimedes technique modified to account for water absorbed by the char during immersion. This technique was verified by dimensional measurements when the residual char was sufficiently contiguous and intact. The errors of measurement are at least one order of magnitude smaller than the range of observed char density.

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[1]Research physicist and electronic technician, respectively, located at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana.

Use of trade or firm names is for reader information only, and does not constitute endorsement by the U.S. Department of Agriculture of any commercial product or service.

The resulting data for "char" are presented in tables 1 and 2; the density distributions are plotted in figure 1. We could find no significant correlation of char density with initial wood density, burn time, or windspeed. Our first speculation was that this wide range of densities is due to variation in the amount of heavy tars and waxes that are collected in the char as they diffuse away from the combustion zone. Several additional char samples were prepared and analyzed by means of the Reaction

Table 1.--*Density measurements of birch char*

Burn No.	Initial diameter	Initial density	Wind-speed	Burn time	Char density
	Cm	*G/Cm*^{3}	*Mi/h*	*Min*	*G/Cm*^{3}
22	2.52	0.638	0	1.0	0.23
23	2.55	.618	0	2.0	.22
24	2.41	.634	0	3.0	.19
25	2.39	.629	0	4.0	.26
26	2.43	.605	0	5.0	.28
27	2.48	.572	0	6.0	.18
55	2.50	.557	5	.5	.26
56	2.50	.554	5	.5	.18
9	2.49	.598	5	1.0	.23
57	2.51	.556	5	1.5	.28
58	2.50	.553	5	1.5	.20
10	2.50	.601	5	2.0	.31
59	2.50	.572	5	2.5	.21
11	2.49	.602	5	3.0	.23
60	2.41	.583	5	3.5	.36
72	2.46	.611	5	3.5	.20
12	2.49	.595	5	4.0	.24
73	2.45	.597	5	4.0	.27
61	2.45	.568	5	4.5	.26
74	2.45	.600	5	4.5	.21
13	2.49	.581	5	5.0	.15
75	2.41	.619	5	5.0	.30
62	2.42	.587	5	5.5	.30
76	2.50	.606	5	5.5	.25
14	2.51	.619	15	1.0	.19
15	2.50	.615	15	2.0	.31
16	2.48	.577	15	3.0	.21
17	2.47	.588	15	3.0	.16
35	.99	.682	2	1.0	.12
36	.99	.681	2	1.0	.22
37	1.22	.665	2	1.0	.17
38	1.21	.709	2	1.0	.22
39	2.49	.525	2	1.0	.24
40	2.48	.527	2	1.0	.22
50	2.41	.665	2	2.0	.28
51	2.39	.554	2	2.0	.23
52	2.49	.708	2	2.0	.25
53	2.55	.729	2	2.0	.24
54	2.40	.566	2	2.0	.20

Coulometer[2] for volative combustion products. The result of this test was negative; the char held no tars or combustion products that vaporize below 500° C.

The implication is that a probabilistic density distribution of residual carbon remains as char after a process of incomplete combustion. If so, the effect should be significant to fire modelers, particularly those concerned with energy balance in combustion of solid fuels.

Table 2.--*Density measurements of pine char*

Burn No.	Initial diameter	Initial density	Wind-speed	Burn time	Char density
	Cm	*G/Cm³*	*Mi/h*	*Min*	*G/Cm³*
28	2.50	0.481	0	1.0	0.20
29	2.51	.469	0	2.0	.12
30	2.48	.432	0	3.0	.17
31	2.49	.438	0	4.0	.15
32	2.47	.475	0	5.0	.22
33	2.50	.473	0	6.0	.14
34	2.49	.480	0	15.0	.34
63	2.46	.470	5	.5	.17
1	2.51	.465	5	1.0	.15
64	2.42	.488	5	1.5	.21
2	2.54	.464	5	2.0	.17
65	2.40	.486	5	2.5	.19
3	2.50	.474	5	3.0	.29
4	2.49	.465	5	3.0	.16
66	2.45	.471	5	3.5	.31
5	2.53	.462	5	4.0	.17
67	2.45	.463	5	4.5	.14
68	2.41	.491	5	5.0	.17
69	2.41	.464	5	5.5	.11
6	2.41	.487	5	6.0	.29
70	2.45	.449	5	6.5	.10
7	2.42	.486	5	7.0	.22
71	2.41	.460	5	7.5	.19
8	2.50	.457	5	8.0	.36
18	2.45	.482	15	1.0	.18
19	2.49	.477	15	2.0	.26
20	2.45	.488	15	3.0	.15
21	2.51	.462	15	3.0	.07
41	1.30	.483	2	1.0	.13
42	1.29	.527	2	1.0	.14
43	2.44	.451	2	1.0	.10
44	2.48	.427	2	1.0	.14
45	2.48	.427	2	2.0	.15
46	2.49	.439	2	2.0	.16
47	2.58	.477	2	2.0	.20
48	2.53	.507	2	2.0	.22
49	2.50	.519	2	2.0	.17

[2] R. A. Susott, F. Shafizadeh, and T. Aanerud. A quantitative thermal analysis method for combustible gas detection. Manuscript in preparation, Northern Forest Fire Laboratory, Missoula, Montana.

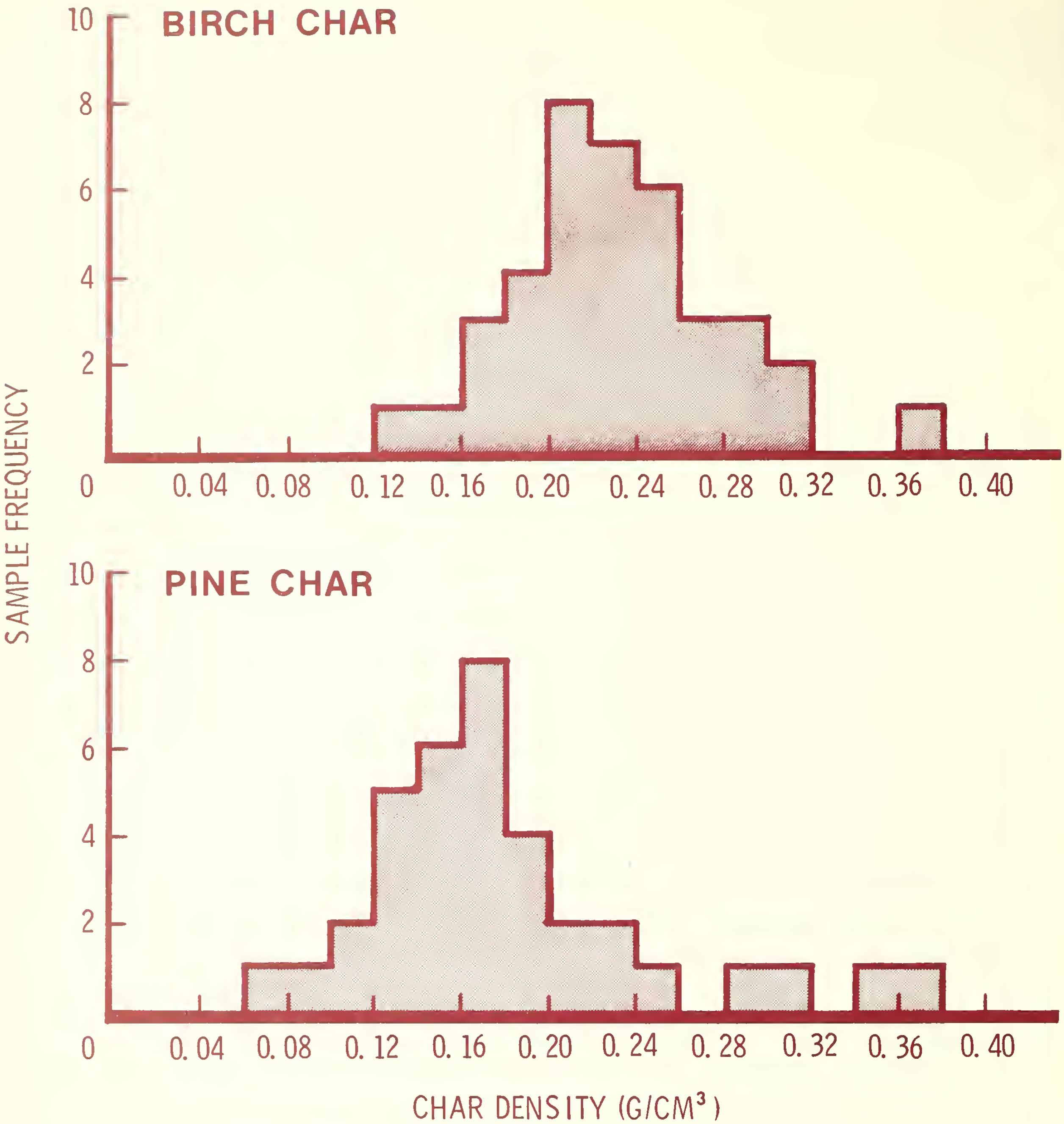

Figure 1.--Density distributions of char formed on birch and pine dowels.

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ESTIMATING EFFECT OF TIMBER HARVESTING LEVELS ON EMPLOYMENT IN WESTERN UNITED STATES

Enoch F. Bell[1]

ABSTRACT

Discusses and presents methods for predicting changes in employment in wood products industries, and total community employment, as the level of timber harvesting rises or falls.

KEYWORDS: employment impacts, timber harvesting.

Forest Service administrators have traditionally been concerned with the stability and economic welfare of communities and individuals near the National Forests. Such statements as "provide public services, income, jobs, and amenities in rural areas..., seek opportunities for development of forest based enterprises..., and identify and promote opportunities for community development," (USDA Forest Service 1974) describe Forest Service concerns. How these concerns should be incorporated in the decision-making process and environmental impact statements is not well established.

This note discusses one aspect of economic welfare, employment, with respect to timber harvesting decisions. It will identify situations in which harvest decisions will affect employment, predict employment changes in the wood products industries because of changes in timber harvest, and show the effect of changes in this employment on employment in other sectors of the local economy. Timber and land-management planners can use the suggested procedures to portray the employment effects of alternative harvest levels.

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[1]The author is principal economist, located at Intermountain Station's Forestry Sciences Laboratory, Missoula, Montana.

WHEN TO CONSIDER EMPLOYMENT EFFECTS

Whether a proposed action significantly affects local employment depends upon a number of criteria. First, does the proposed action actually change the harvest level or only the limits on the harvest level? For instance, an increase that cannot be sold because of budget restrictions will not affect the amount being cut unless the budget is increased and buyers are available. No change in harvest will have no effect on employment.

The second consideration is the relative importance of the agency or firm providing timber to industry. If the industry receives a large proportion of its raw material from one forest owner, then changes in harvest level by that owner will have considerable effect on the industry, even with some substitution from other sources. Table 1 shows for selected Oregon counties the proportion of the total harvest provided by National Forests that is processed by the forest products industry. For counties such as Baker and Crook, changes in National Forest harvest may be critical because industry appears to have few alternative sources of timber. When does the proportion of a total harvest provided by one firm or agency become critical? My experience indicates that industry shows concern when more than 40 to 50 percent of its raw material is supplied by one source.

The final consideration is the percentage of local employment provided by the forest products industry. If the industry provides a small portion of total employment, changes in its employment will have little effect on the community. "Substantial portion" can be difficult to define; however, the forest products industry is generally regarded as a major employer in any county where it employs 20 percent of the work force. Figure 1 identified counties in the western United States in which the forest products industry provides, 10, 20, and 30 percent of the total employment as determined by the 1970 Census of Population. The critical counties are located in western Montana, northern Idaho, Washington, Oregon, and northern California.

Impact on timber supply, proportion of timber supply, and significance of wood products labor force--these criteria can indicate how harvest flows will affect employment. When an alternative affects a major portion of the local timber supply and the wood products industry provides a significant amount of the local employment, then a detailed study of the employments effects is warranted.

Table 1.--*Oregon counties in which National Forests supplied more than 50 percent of the timber processed by primary wood products industries in 1972 (calculated from Schuldt and Howard 1974).*

County	Total wood processed	National Forest
	M bd. ft.	*Percent*
Baker	102,293	90
Clackamas	352,573	63
Crook	156,000	94
Curry	202,924	73
Deschutes	214,000	69
Grant & Harney	297,754	91
Hood River	90,111	61
Lake	117,400	60
Umatilla & Morrow	109,197	55
Union	196,409	69
Wallowa	35,760	71

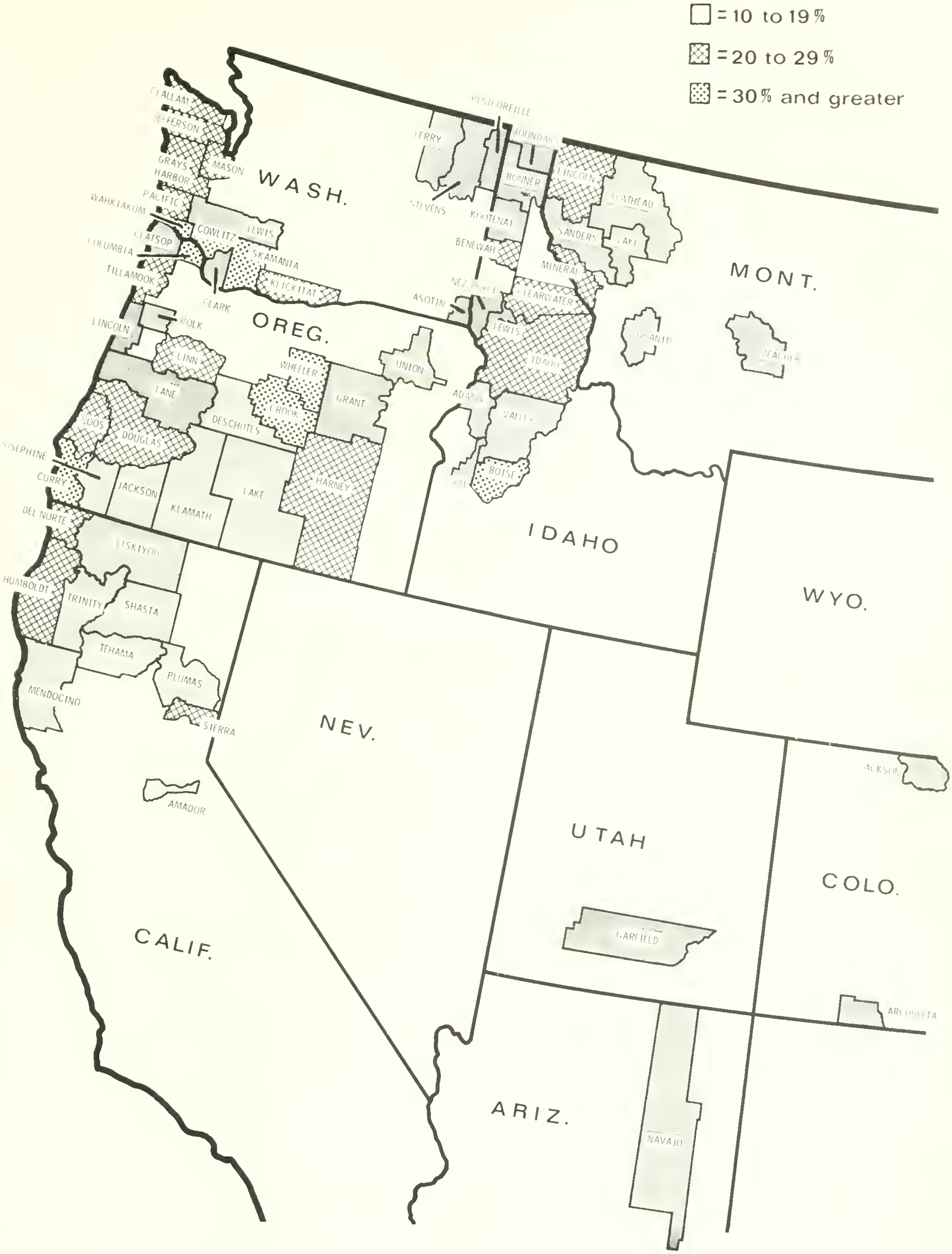

Figure 1.--Counties where wood products and paper industries provide 10 percent or more of all employment.

CALCULATING FOREST INDUSTRY EMPLOYMENT EFFECTS

In forest industries, labor can be expressed as the number of employees required per million board feet of timber processed. (Wall and Oswald 1975). This ratio can be used to estimate the number of employees that could be supported by a specific harvest level. Because it is derived by dividing total employment into total timber input, the ratio of employment to wood consumption is an average.

Table 2 shows employment-wood consumption ratios derived from various sources for States where forest products industries provide a major source of employment. To use these ratios, one estimates the expected change in harvest measured in log scale and multiplies this figure by the ratio for the area being considered. The result is the change in employment for the primary forest products industry. For example, if one alternative produces a 2 million board-foot reduction in National Forest harvest in western Oregon, then the number of primary processing jobs affected would be approximately 2 by 6.6 = 13.2.

Table 2.--*Average forest products industry's employment-input ratios for selected western States. (Calculated from: Idaho - Schuster and others 1975; California, Oregon, and Washington - Wall and Oswald 1975; Montana - Johnson 1972; using the procedure for published data shown in the appendix.)*

State	Ratio - employees per million board feet local scale
Idaho	7.0
California	5.7
Montana	6.0
Oregon - Eastern	6.1
Western	6.6
Washington - Eastern	6.8
Western	8.6

The employment-wood consumption ratio must be used with care when predicting employment changes. First, estimates of employment changes are based on changes in harvest of a single agency or National Forest as in the example just presented. This assumes that there will be no substitute wood supply. In cases where there is little private timber, where the industry is dependent on public timber, and where timber cannot be easily imported, this assumption may be valid. However, a recent unpublished study indicated that in the western pine region a 25 percent reduction in the supply of National Forest timber would be partly offset by a 10 percent increase in private harvest over the shortrun. (Darius M. Adams, 1976. Further simulations of the price effects of shifts in National Forest timber harvest schedules. Unpublished report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.) Instead, prediction of employment changes should be based on estimates of changes in total local timber supply if it can be estimated.

Second, one must assume that the employment-wood consumption ratio represents all the wood products plants in a local area. This may not be the case. Employment-wood consumption ratios vary by industry (sawmills, logging, veneer mills, etc.), by location, and by individual firm. These problems can be avoided by calculating employment-wood consumption ratios for the local mills rather than using the figures in table 2. Furthermore, changes in harvest size or quality may affect different sectors of the primary wood products industry in different proportions. A detailed discussion of the procedure can be found in the appendix.

A third assumption is that employment-wood consumption ratios change little over time because of the slow rate of technological change. This is a safe assumption for the short run; however, long-range projections may warrant some adjustment. A weighted composite of the data presented by Wall and Oswald (1975) for California, Oregon, and Washington indicates that the average reduction in the employment-wood consumption ratio is approximately 10 percent per decade. Again, this average can vary by industry, with logging showing the least change over time.

Fourth, one must assume that the wood consumption associated with the marginal employee--the last hired or the first fired--is the same as the average wood consumption per employee. This is probably not true for the industry as a whole and may not be true for individual firms. Variations in employment-wood consumption ratios between firms are known to exist and lack of variation in an individual firm would require stringent conditions concerning the production functions and the relative unit values of employment and wood consumed. Unfortunately little or no research has been done to show the error in employment projections caused by assuming that the marginal and other employees are similar in wood consumption. For those unwilling to make this assumption, a procedure avoiding it is presented in the appendix under calculation of a marginal employment-wood consumption ratio using original data.

Together these assumptions indicate that employment-wood consumption ratios must be used with care. However, for situations in which little data are available or the data are costly to obtain, ratios shown in table 2 indicate how timber supply may affect employment.

ESTIMATING SECONDARY EMPLOYMENT

Basic industries are those that provide income and jobs to the community through exports; this income and employment, in turn, generate income and employment in nonbasic industries, those that serve the local community. Thus, the economy is assumed to be dependent on the basic industries for its existence. Although this view might be questioned, many "ghost" towns in the West were created when basic industries such as mines or sawmills closed down. Generally wood products industries are considered to be basic.

The relationship between employment in the basic and nonbasic industries in the local economy is commonly expressed by means of a ratio called "the employment multiplier." This multiplier is useful in predicting the effects employment changes will have on community employment. To do this, one calculates the change in a basic industry and multiplies this change by the employment multiplier to get the change in community employment. For instance, the example in the previous section showed that a 2-million-board-foot decrease in the harvest reduced the number of wood products industry positions by 13 in western Oregon. Thus, if this reduction in basic industry employment opportunities occurred in Coos County with its multiplier of 2.46, the total number of positions that might be eliminated by this reduction would be 2.46 by 13 = 31.98. Thirteen of these positions would occur in the wood products industry and 19 would be in service industries such as retail stores, gas stations, clinics, schools, and so on. One can assume that the multiplier remains fairly constant over time (Tiebout 1960).

There are numerous ways of defining basic and nonbasic employment and calculating the employment multiplier. One way is to define certain industries such as agriculture, mining, and manufacturing to be basic because they usually ship most of their production outside the local area. Convery (1973), for example, has advocated this technique using published data for small rural communities where these industries are almost always the basic ones. This technique is illustrated in table 3, which provides employment multipliers for counties where the wood products industries employed at least 10 percent of

Table 3.--*Wood products employment and employment multiplier by selected counties for 1970 in western United States*

County by State	Wood[1] products employees	Multiplier[2]
Alaska (Districts)		
Haines	136	3.04
Ketchikan	636	3.68
Outer Ketchikan	54	2.31
Prince of Wales	565	1.30
Sitka	626	3.08
Wrangell-Petersburg	464	1.83
Arizona		
Navajo	1,236	3.73
California		
Amador	452	3.69
Del Norte	1,200	2.76
Humboldt	7,193	3.25
Mendocino	3,302	3.26
Plumas	678	3.97
Shasta	3,454	4.43
Sierra	189	2.96
Siskiyou	2,279	2.87
Tehama	1,897	2.58
Trinity	458	2.91
Colorado		
Archuleta	169	2.40
Jackson	79	2.25
Idaho		
Adams	159	2.29
Benewah	499	2.29
Boise	186	1.77
Bonner	904	3.07
Boundary	350	3.00
Clearwater	789	3.06
Gem	609	1.99
Idaho	865	2.23
Kootenai	1,229	3.44
Lewis	158	2.36
Nez Perce	1,679	3.59
Valley	223	3.17
Montana		
Flathead	1,433	3.36
Granite	162	2.32
Lake	459	2.86
Lincoln	1,572	2.68
Meagher	158	1.80
Mineral	255	3.10
Sanders	424	2.63
Oregon		
Clatsop	1,156	3.08
Columbia	3,008	2.29
Coos	5,885	2.46
Crook	1,162	2.14
Curry	1,460	2.09
Deschutes	1,710	3.70
Douglas	6,803	2.49
Grant	400	2.37
Harney	697	2.04
Jackson	4,385	3.65
Josephine	1,845	3.26
Klamath	3,181	2.78
Lake	382	2.23
Lane	13,401	3.64
Lincoln	1,554	3.47
Linn	5,603	2.35
Polk	1,747	3.08
Tillamook	1,469	2.37
Union	954	3.62
Wheeler	237	1.69
Utah		
Garfield	132	2.85
Washington		
Asotin	747	3.54
Clallam	3,094	2.78
Clark	5,834	3.09
Cowlitz	8,087	2.28
Ferry	147	2.03
Grays Harbor	5,776	2.58
Jefferson	928	2.94
Klickitat	1,016	2.38
Lewis	3,007	2.89
Mason	1,702	2.51
Pacific	1,451	2.19
Pend Orielle	263	2.73
Skamania	588	2.15
Stevens	730	2.67
Wahkiakum	464	1.69

[1] Calculated from: Ashby, L. D., and D. W. Cartwright. 1975. Regional employment by industry 1940-1970. 542 p. U.S. Dep. Comm., Bur. Econ. Anal.

[2] Calculated by dividing total county employment by the sum of the employment in the agriculture, mining, and manufacturing industries and the federal military. Employment data were taken from the citation in footnote 1.

employment. The multipliers were calculated from the 1970 Census of Population (Ashby and Cartwright 1975) by dividing the sum of the county employment in the agriculture, mining, and manufacturing sectors plus the Federal military into the total number of employees in the county. For instance, in Coos County, Oregon, in 1970, employment was as follows: agriculture (967), mining (17), manufacturing (6,960), and Federal military (340). The sum of these sectors (8,284) provides an indication of the basic employment. This figure divided into the total county employment of 20,402 produces the employment multiplier of 2.46 as shown in table 3.

A more accurate way of identifying the basic employment is by determining the proportion of products that each firm exports through a survey of individual firms in a community. Multiplied by a firm's total employment, this proportion will show the basic employment of that firm, assuming employment is proportional to production. Dividing the community's total employment by its basic employment, will provide an accurate multiplier.

The location quotient (Tiebout 1962) provides another method for defining basic employment using published data. The quotient is calculated by dividing the proportion of total employment an industry provides locally by the proportion that industry provides over a larger region, usually the Nation. If this quotient is greater than one, then some of the local industry's employment is basic. For example, in Clackamas County, Oregon, in 1972 the lumber and wood products industry provided 7 percent of total employment, whereas nationally this industry provided only 1 percent of total employment. The location quotient would be the ratio of these percentages or 7:1. The difference in these percentages (6 percent) multiplied by the total county employment provides the number of basic employees in the lumber and related wood products industry.

This procedure would be repeated for all other industries in the county. The total employment of the county divided by the sum of the basic employees in all industries is the employment multiplier. Data for this technique are available in publications such as the U.S. Bureau of the Census *Census of Populations* and *County Business Patterns*. Maki and Schweitzer (1973) have used this technique in forestry to calculate community dependency.

This technique has certain weaknesses. The multiplier derived from the location quotient is usually too large (Tiebout 1962). Similar techniques have been developed to overcome this problem, but have not received widespread usage.

Furthermore, the size of the multiplier is influenced by the degree of aggregation used in the industrial classification. For example, if all wood products industries are grouped together, the multiplier is apt to be larger than if the multiplier is calculated separately for such industry groups as sawmills, planing mills, logging, and so on. A more serious problem is the assumption that product demands of the local economy are the same as those of the national economy. This is seldom the case in small rural communities, and thus the method may not be applicable here.

A much more complicated and expensive technique for arriving at a multiplier is an input-output study. This technique generally involves a detailed survey of transactions in the local community to determine the inputs and outputs required by each industry in dollar terms. Then summaries of these interactions in the economy are usually calculated in terms of income, which then must be converted to employment to obtain the desired multiplier. Because of the complexity of this technique, interested readers are referred to Darr and Fight (1974) for an example of how to use it in forestry, and to Miernyk (1965) for a complete discussion of the technique and its use.

Input-output studies are generally not transferable. Each local economy is usually so unique that direct transfer may be misleading. Furthermore, even if a study has been done for the county, the wood products industry may not be explicitly identified. Where available with industries suitably defined, input-output studies may provide the best indicators of employment multipliers, but generally it is not feasible to develop one just to show timber industry impacts because of the time and expense involved.

Which of the above techniques is used to calculate the employment multiplier depends upon the time and money available and the precision required. Generally, time and money are too restricted for an input-output study. However, if a current study defines the forestry sectors adequately for the relevant region, then it should be used. The most desirable alternative to an input-output study would be a survey of basic employment. This approach also may require more time and money than is available and force the use of published data. For large communities, the service, manufacturing, and raw material sectors all export some commodities; none are entirely basic industries. Thus, it is usually most practical to use the location quotient method even though it overestimates the multiplier. For small rural communities, the technique that simply defines certain sectors as basic provides an adequate indicator of the employment multiplier for most forestry planning situations. The sectors usually defined as basic are the agriculture, mining, and manufacturing sectors; Federal and State employees are often added if known, because their incomes come from an external source.

CONCLUSIONS

Impact of timber management decisions on community employment should be considered when harvest levels will fall, the substitute timber supply is small, and the wood products industry provides a significant proportion of the community's employment. The change in wood products employment from changing timber supply can be calculated by multiplying the employment-wood consumption ratio by the change in quantity supplied. This ratio may be derived from data gathered locally or from published sources. The effect of changes in wood products industry employment on employment in the community is measured by a multiplier. That may be calculated from an input-output analysis, by location quotients, or by simply defining certain industries as basic. In all cases, care must be taken not to attribute excessive precision to the employment impact analysis.

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APPENDIX

Calculating Employment-Wood Consumption Ratios

Two approaches for generating employment-wood consumption ratios are outlined and illustrated below: (1) a fast and cheap method using published data, and (2) a more expensive, time-consuming, and precise one using original data.

Using Published Data (This approach follows that outlined by Gamache in Mason and others [1974] and is used for the calculations in table 2.)

Step 1.--From the equations presented in Wall and Oswald (1975) for Oregon, we get the following ratios for employees per million board feet.

Industry	*Ratio*
Logging	1.46
Sawmills & planing mills	3.49
Veneer and plywood	6.44

Step 2.--From Schuldt and Howard (1974) for Oregon or local Forest data, we get the distribution of the National Forest harvest.

Industry	*Volume (mm bd. ft.)*	*Percent of total*
Sawmill, planing mills, etc.	322,914	77
Veneer and plywood	96,089	2
Total	419,003	100

Step 3.--Assuming changes in harvest will be distributed to the mills in the same proportion as the present harvest, we derive a combined employees per million board-foot ratio:

$$\underset{\text{(logging)}}{1.46} + \underset{\text{(sawmills)}}{0.77 \times 3.49} + \underset{\text{(veneer)}}{0.23 \times 6.44} = \underset{\text{(ratio)}}{5.63}$$

In some cases, employment for pulpmills may also be added if they absolutely depend on the local residues from the veneer and sawmills for wood input. Generally, they have alternative wood supplies so that pulp production and thus employment will probably not change with changes in local harvest.

Using Original Data

Step 1.--From a survey of individual mills, determine the average annual consumption of wood and average annual employment. Divide the number of employees by the amount of wood used to get the average employment-wood consumption ratio for each mill such as is shown in the fictitious example below.

Firm	*Ratio*
Average of eight local loggers	1.5
Silesia Milling Co.	3.0
Sidney Scrag Mill	2.1
Porter Veneer and Plywood, Inc.	8.6

A better procedure if the data can be obtained is to calculate the marginal rather than the average employment-wood consumption ratio. This could be obtained by observing the effect on employment of year-to-year changes in mill inputs, assuming no change in technology. Or it could be arrived at by asking the mill operator how employment would change with a given change in his wood supply.

Step 2.--Estimate the proportion of increase or decrease in harvest going to each mill. This could be done on the basis of past harvest or it could reflect mill bidding power or the type of raw material involved. For the example, we will assume a decrease in the number of large logs will prevail.

Firm	*Past harvest (percent)*	*Anticipated harvest (percent)*
Silesia Milling Co.	30	40
Sidney Scragg Mill	20	20
Porter Veneer & Plywood, Inc.	50	40

Step 3.--Apply the same principles as in the previous step 3.

$$\underset{\text{(logging)}}{1.5} + \underset{\text{(sawmills)}}{(0.4 \times 3.0 + 0.2 \times 2.1)} + \underset{\text{(veneer)}}{0.4 \times 8.6} = \underset{\text{(ratio)}}{6.6}$$

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REGENERATION AND EARLY GROWTH ON STRIP CLEARCUTS IN LODGEPOLE PINE/BITTERBRUSH HABITAT TYPE

David A. Perry and James E. Lotan[1]

ABSTRACT

Establishment and growth of seedlings 13 years after strip clearcutting was investigated on a lodgepole pine/bitterbrush habitat type in southwestern Montana. Ingress of new seedlings (all from open-coned lodgepole pine) on areas that had been heavily bulldozer scarified was considerably better than on areas without bulldozer scarification. Seed:seedling ratios (established seedlings) ranged from 625:1 to 2,160:1 on scarified sites, and from 1,876:1 to 6,480:1 on unscarified sites. Only 3 years out of 13 resulted in significant numbers of seedlings being established. Advanced regeneration released by logging was growing as rapidly as seedlings established following logging.

KEYWORDS: lodgepole pine regeneration, lodgepole pine growth, site preparation

Proper site preparation is an important tool in regenerating lodgepole pine stands following logging. Slash disposal methods and site preparation techniques also may affect various parameters of site quality, and thus influence not only the regeneration stage but also growth of the new stand. Studies have shown that lodgepole pine becomes established most easily on disturbed seedbeds (Alexander 1966; Lotan 1964), and that method of slash disposal may influence height growth during the first 2 years following

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planting or direct seeding (Lotan and Perry 1977). However, we have little knowledge concerning long-term effects of different site preparation and slash disposal techniques.

This paper contrasts the effects of extreme soil disturbance (bulldozer scarification) and light soil disturbance on ingress of regeneration and growth of seedlings 13 years after logging.

SITE CHARACTERISTICS

The study area, near West Yellowstone, Montana, is a level plain with virtually no microsite differences. Soils are loamy sands with low water holding capacity formed from alluvial deposits of obsidian and rhyolite (Stermitz and others 1974). Forests are pure, uneven-aged (0 to 230 years) lodgepole pine, with 38 percent of the trees having serotinous cones (Lotan 1967). Habitat type is *Pinus contorta/Purshia tridentata* (Pfister and others 1977). This type occurs near West Yellowstone and has not been defined elsewhere (although it may be similar to lodgepole pine sites which occur on pumice in central Oregon). Average site index (100-year base) is 40. Clearcuts have a sparse cover, primarily composed of various sedges and grasses. Scattered shrubs of bitterbrush (*Purshia tridentata*) also occur. Elevation of the sites is 2,188 ± 8 m.[2] The area has a continental mountain climate, with cold winters and a short growing season. From 1962 through 1975, an average of 14 days during June, July, and August had below freezing temperatures. Growing season (June-August) precipitation during the same period averaged 147 mm, 51 percent of which occurred in June, 22 percent in July, and 27 percent in August (U.S. Weather Bureau 1962-1975).

PROCEDURE

Strips were logged in May 1963. Two of them (numbers 1 and 3) were approximately 80 by 500 m, and one (number 2) was 120 by 500 m in size. All strips were oriented perpendicular to prevailing winds (southwesterly). On roughly 25 percent of each strip, slash was burned in place, and on the remainder, it was windrowed (using a bulldozer) and burned. In the windrowing process, the top few centimeters of soil and all competing vegetation were removed. All burnings were done in September 1963. Closed cones in the slash had not opened; thus input of seed from this source was negligible.

Trees had been felled so that they lay in somewhat of a herringbone pattern; that is, slash was concentrated in strips rather than distributed randomly. Therefore, the "burned in place" treatment was not exactly a broadcast burn (roughly 20 percent of the area was burned). Principal differences between the two treatments were (1) the degree of soil disturbance associated with slash cleanup, and (2) the presence of advanced regeneration (residual trees) on the "burned in place" and not on the "dozer-piled" treatment (any present were uprooted in the piling process).

Density, stocking, and growth were measured in late summer and early fall of 1976. Sampling lines (10 in windrowed areas and 4 in broadcast burns) were laid out randomly, perpendicular to the long axis of the strip. On each of these, a plot was established approximately every 8 m (distances were paced). Each plot was circular, 16 m^2 in area, and was divided into four quadrants of 4 m^2 each. The number of trees in each quadrant was counted. Density was determined from the total count, and stocking from the percentage of quadrants having trees. A circular 4 m^2 plot was laid out within and having the same center point as the 16 m^2 plot, and all trees within it were felled. Age at ground level was determined from ring count with a hand lens, and total height was measured to the nearest centimeter.

---

[2] 1 m = 3.28 feet; 10,000 square meters (m^2) = 1 hectare (ha) = 2.47 acres; 4 m^2 = 1 milacre; 1 cm = 0.4 inch; 1 mm = 0.04 inch; 1 km = 0.62 mile.

Twenty-four advanced trees (established before logging) were selected to represent a range of sizes and were felled to determine their response to release. None of these were located within areas where slash concentrations had been burned, and so should not have been affected by fire. Age, diameter, and radial growth in the past 10 years were determined at ground level--0.5 m, 1 m, and every subsequent 1 m for the total height of the tree. The same measurements were made on 10 trees of similar height growing under the adjacent forest canopy.

Seedfall in 1963, 1965, and 1968 was determined from 1-m^2 seed traps placed at 22-m intervals across each strip (eight traps per strip). Rainfall data are taken from a U.S. Weather Bureau weather station at West Yellowstone, about 8 km from the study sites. Comparison with a standard rain gage operated on one of the strips from 1962 through 1967 shows that West Yellowstone rainfall was representative of that on the study sites (r^2 equal to or greater than 0.89 in all months except August, when it was 0.67).

Stocking and density differences between the two site preparation techniques within each strip were compared using a "t" test. Because of site uniformity, no position effect is expected in this analysis. Growth differences between released residual trees and trees under the forest canopy were also compared by "t" test. Multivariate-regression analysis (Grosenbaugh 1967) was used to test the relation between seedling establishment and weather variables.

RESULTS AND DISCUSSION

Stocking and Density

Dozer-piled (DP) areas averaged 1,333 trees per ha with 24 percent stocking. (To find trees per acre, multiply per ha value by 0.39). Burned-in-place (BP) areas averaged 645 trees per ha, approximately 30 percent of which was advanced regeneration, with 15 percent stocking. However, there was considerable difference in the response of individual strips (fig. 1). In strip 1, density and stocking are better on DP than on BP areas, and apparently also in strip 2 (table 1). In strip 3, although there are nearly one-third more new seedlings on DP than on BP areas, no statistical difference can be shown. Differences among the strips reflected changes in seedling density in both BP and DP areas. The high density in the BP treatment in strip 3 was partially due to a large amount of advanced regeneration. Seed production was generally highest surrounding strip 1 and lowest surrounding strip 2; however, this apparently had little influence on relative stocking among the strips.

Table 1.--*Probability that treatment effects are different*

Treatment	Strip 1	Strip 2	Strip 3
Density			
including advanced regeneration	>0.999	0.92	0.62
not including advanced regeneration[1]	>.999	.93	.41
Stocking (including advanced regeneration)	>.999	.92	.67

[1] Mean density without advanced regeneration was estimated by subtracting the proportion of trees established before logging, determined by ring counts on felled seedlings, from the density obtained by the count within 16-m^2 plots. (Proportion determined for each strip separately.)

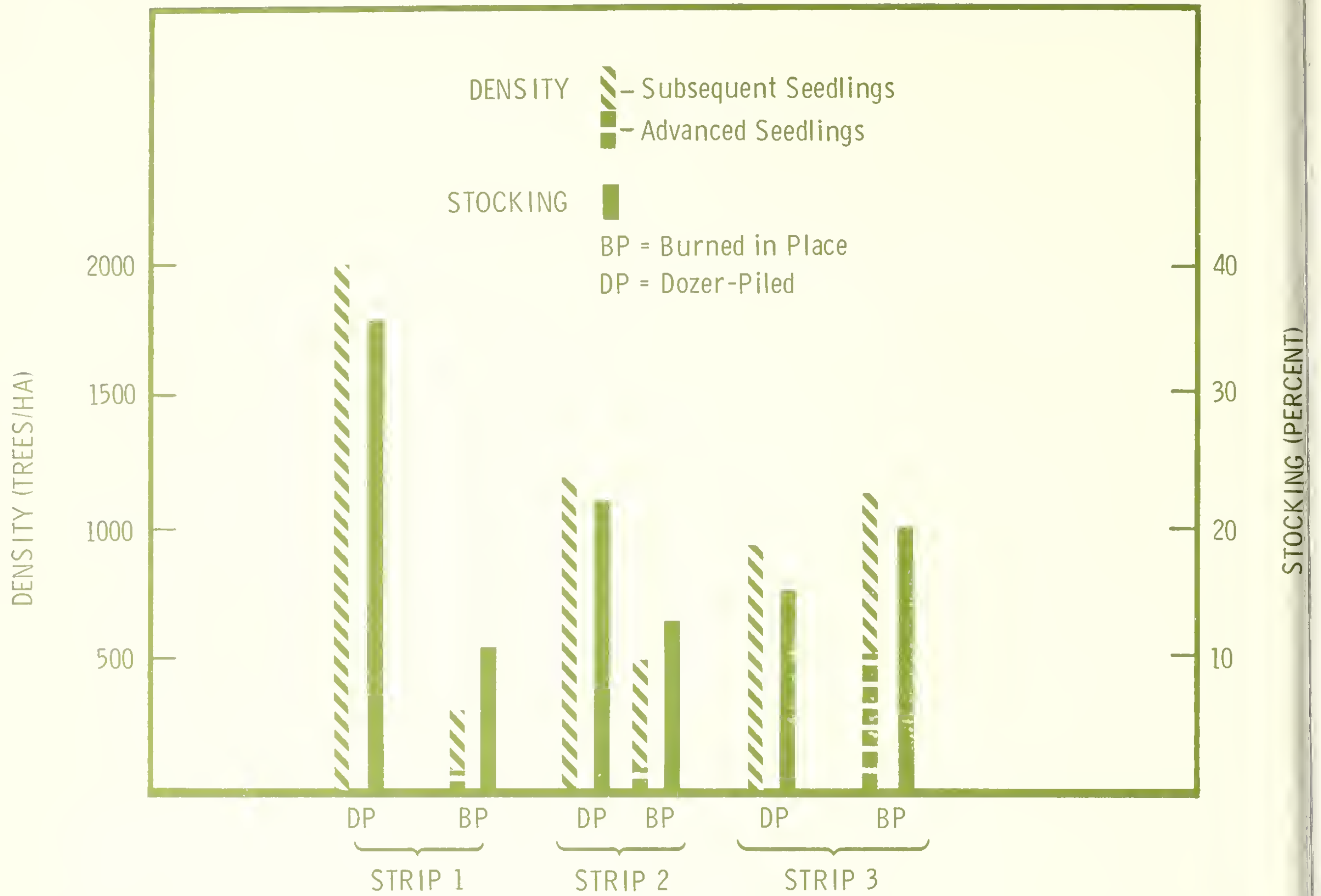

Figure 1.--Density and percent stocking of regeneration on three strip clearcuts, by site preparation technique.

Seed:seedling ratios (seedlings surviving to 1976) for the 3 years of recorded seedfall (1963, 1965, 1968) ranged from 625:1 to 2,160:1 on DP areas, and from 1,876:1 to 6,480:1 on BP sites. Ratios within 8 m of the south timber edge were approximately 10 times higher than beyond, despite the ameliorating effect of shade, which may have benefited competing vegetation more than it did tree seedlings. Nevertheless, in DP areas, 37 percent of seedlings were in this area, reflecting the large amounts of seed falling near the timber edge (fig. 2). Beyond 8 m, seedling density was fairly evenly distributed across the strips. Similar clumping of seedlings near the south timber edge did not occur on BP areas, possibly because of the extremely low number of microsites suitable for seedling establishment on the undisturbed seedbeds.

Only 3 years out of 14 resulted in significant seedling establishment. These followed one another, resulting in a normal curve of seedling ingress (fig. 3). Crossley (1976) has reported the same pattern on a number of lodgepole pine clearcuts in Alberta: seedling establishment is low in the first few years following harvest, increases rapidly, peaks about the 6th year, then declines rapidly. Although we cannot explain this pattern, it may be related to reoccupation of the site by other vegetation, which provides increasing cover (site amelioration) up to a point, after which competitive effects begin to dominate. Weather variables alone explained very little of the year-to-year variation in seedling establishment.

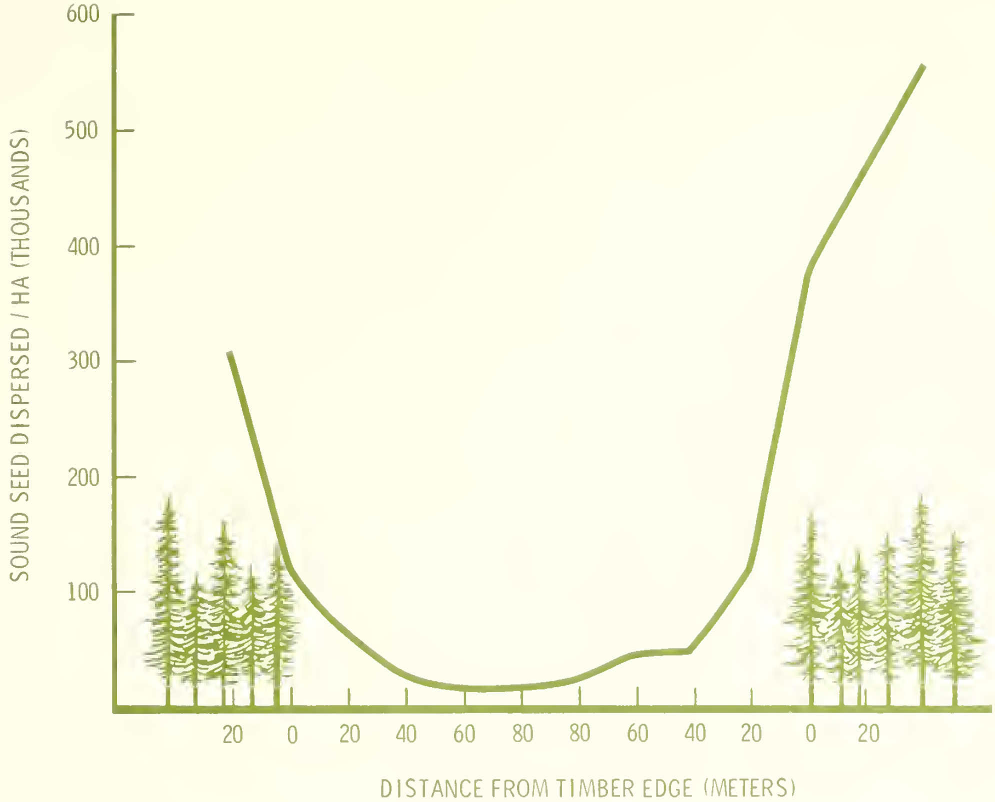

Figure 2.--[illegible] *on three sites* [illegible] *West* [illegible]*,* [illegible] *pole pine. Thirty-*[illegible]

Figure 3.--[illegible]

Seedling Growth

Seedlings on BP areas averaged 17 percent taller than those in DP treatments (108 cm vs. 85 cm; significant at the 0.01 level); due solely to the advanced regeneration on the BP sites. Average growth rate of seedlings established since logging was not different on the two treatments (0.10 m/yr for both). Variation among seedlings in growth rate was also similar--the standard deviation 4.4 cm/yr on BP areas, and 4.0 cm/yr on DP areas.

Released trees are growing at a rate equal to or greater than that of seedlings established since logging, which may be partly due to the fact that trees accelerate growth after a certain size regardless of treatment. Even under the forest canopy, trees sharply increased their height growth rate after reaching 1 m (significant at the 0.001 level); however, they still did not match the growth rate of trees released by logging. In 1976, leader growth averaged 23 cm on released trees and 15 cm on trees under the forest canopy (difference significant at the 0.01 level). Age at the time of release (up to 55 years, maximum measured) did not seem to be a factor in ability to respond.

Average diameter growth per year over the past 10 years was 3.8 mm for released trees and 1.6 mm for trees growing under the forest canopy (difference significant at the 0.001 level). Among released trees, radial increment at 1 m averaged 27 percent greater and at 2 m, 70 percent greater than that at 0.5 m and ground level. Therefore, "butt swell," which has been noted in released trees of other species did not occur in this case.

At the densities experienced here, crowding had very little effect on seedling growth. Tree density in a 4-m^2 plot centered on the sample tree (range: 1 to 16 trees per plot) did not affect 1976 leader growth (r^2 = 0.003), and had a slight negative effect on average yearly increment (r^2 = 0.23).

Suppressed lodgepole pine has also been shown to respond to release in British Columbia (Keith Illingworth. 1961. Lodgepole pine in the southeastern interior of British Columbia: a problem analysis. B.C. For. Serv.) and in the Blue Mountains of Oregon (Trappe 1959). This may be generally true, providing trees have a vigorous crown and have not been suppressed for longer than 50 or 60 years. However, we don't know how many years an older tree that is released can maintain its accelerated growth. Until we have this answer, it should be assumed that trees suppressed for longer than 10 or 15 years will not sustain rapid growth for a significant period after release.

CONCLUSIONS

Several previous studies have shown that lodgepole pine regenerates better on a disturbed seedbed than on an undisturbed seedbed (see citations in the introduction) Our study generally supports this theory but on our sites the degree of establishment on disturbed and undisturbed areas varied considerably. We are unable to explain the differences in our three strips; however, we are still seeking the answer.

Our results strongly indicate that, on these sites, seedlings present in the stand at the time of logging will respond to release and may form a very important component of the regeneration. The presence of advanced regeneration should be considered when evaluating the degree of site disturbance needed. If advanced regeneration is left, it is critically important that all sources of dwarf mistletoe infection be removed. Where the understory is heavily infected, it is probably better to remove all residual trees.

This habitat type is exceptionally droughty and nutrient poor. The level of vegetative competition is low compared to more productive sites. Therefore, use caution when extrapolating these results to other environmental conditions.

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FIFTH-YEAR SEED:SEEDLING RATIOS OF LODGEPOLE PINE BY HABITAT TYPE AND SEEDBED PREPARATION TECHNIQUE

James E. Lotan and David A. Perry[1]

ABSTRACT

After the first and fifth growing seasons (nine seedbed treatments in each of three habitat types), seed:seedling ratios of lodgepole pine were inversely related to moistness of the site. On Pinus contorta/Purshia tridentata *(droughty) and* Pseudotsuga menziesii/Calamagrostis rubescens *(medium moist and high competition), acceptable seed:seedling ratios were not attained without thorough site preparation. Cultivating gave the lowest seed:seedling ratio on the Pico/Putr type (301 seed to establish one seedling), followed by spraying (512:1), furrowing, and trenching (both 550:1). On the Psme/Caru type, cultivating, spraying, brushblading, and scalping all gave ratios less than 100:1. Burning was not desirable on this type, probably because it stimulated grass growth. On the cool and moist* Abies lasiocarpa/Vaccinium scoparium *type, ratios on all seedbeds might produce acceptable stocking levels (assumed to be 3,000 trees per hectare (1,200 per acre) at age 5) depending on available seed. On this latter type, lack of site preparation may be a useful tool in controlling overstocking.*

Survival in the fifth year (as a percentage of seedlings alive in the first year) varied from 0 to 33 percent on Pico/Putr, 2 to 60 percent on Psme/Caru, and 53 to 143 percent (net ingress of seedlings) on Abla/Vasc habitat types.

KEYWORDS: lodgepole pine, regeneration, seed:seedling ratios, seedbed preparation

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To evaluate the probability of successful natural regeneration on a particular site, a manager must estimate (1) available seed and (2) seed:seedling ratios after stocking levels have become reasonably stable (seed:seedling ratio indicates the number of seed required to establish one seedling). The latter will vary depending on a number of environmental and management factors, among them habitat type and the type of slash disposal-seedbed preparation technique that the manager chooses.

This note reports fifth-year seed:seedling ratios of lodgepole pine on nine seedbed treatments in each of three habitat types in southwest Montana and southeast Idaho. First-year results were reported by Lotan (1964) and will also be summarized herein.

METHODS

Experimental Design and Study Areas

Nine seedbed treatments were replicated three times in a randomized block design on each of three physiographic areas (table 1).

Table 1.--*Location and characteristics of experimental areas*

Area and National Forest	Soil	Habitat type (Pfister and others 1977)	Slope	Elevation
			Percent	*m*
West Yellowstone, Gallatin N.F.	Alluvial obsidian sands and gravel	*Pinus contorta/ Purshia tridentata*	<5	2,030
Island Park, Targhee N.F.	Alluvial rhyolitic loam over cobble	*Pseudotsuga menziesii/ Calamagrostis rubescens*	5 to 15	1,970
Moose Creek Plateau, Targhee N.F.	Gravelly clay loam developed from various volcanic rocks	*Abies lasiocarpa/ vaccinium scoparium*	5 to 15	2,364

Treatments

Rectangular 8-m^2 plots (2×4 m)[2], oriented with their long axes in a north-south direction, were treated during the summer of 1961 as follows:

1. Check. Natural undisturbed duff.

2. Burned. Areas where slash had been piled and burned.

3. Disked. Plots were disked in an east-west direction by a lightweight disk harrow.

4. Scalped. Area was stripped of all vegetation by using a shovel to simulate scalping by a dozer blade.

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[2] 8 m^2 = 2 milacres; 1 m = 3.28 feet; 1 cm = 0.4 inch; 1 kg = 2.2 pounds; kg/ha = $0.9 \times$ lb/acre.

5. Scalped and cultivated. Area was stripped of all vegetation, and the soil was loosened to a depth of 15 cm by using a shovel.

6. Scalped, cultivated, and sprayed. Area was treated as in treatment 5 and in addition was sprayed with Dalapon grass killer (2,2-dichloropropionic acid) at a rate of 14 kg/ha.

7. Simulated brushblade scarification. Quadrat was partially scalped (about 90 percent of the area) of vegetation, and small trenches (about 40 cm apart and 2 to 7 cm deep) were dug with a mattock in an east-west direction.

8. Furrowed. Trenches 7 to 10 cm deep were dug in an east-west direction, leaving a sharp, perpendicular edge to the south to provide maximum shade to seedlings in the trench.

9. V-shape trenched. Trenches 7 to 10 cm deep were dug in an east-west direction, leaving a 45-degree angle to both the north and south to provide seedlings with minimal shade.

Seeding

The lodgepole pine seed used in this study were collected on the Targhee National Forest in 1958 at an elevation of 2,100 m. Seed were 55 percent viable (standard germination test after Endrin and anthraquinone treatment) and were treated with 17.5 percent anthraquinone and 2.5 percent Endrin (clean, untreated seed basis) to repel birds and rodents. The seed were broadcast sown in October 1961. They were not covered, as the intent was to simulate natural regeneration rather than direct seeding. A large amount of seed (2,200 viable seed per 4 m^2, equivalent to 2,200,000 seed per acre) was used to insure an adequate seedling catch and thereby permit statistical analysis of data from all treatments. Failure on adverse seedbeds would have hindered analysis of data. Plots were located at least 150 m from the nearest timber edge, well beyond the distance that seed are normally transported by wind. Therefore, we feel that input of seed from the adjacent timber was negligible. Nevertheless, the seed: seedling ratios calculated herein should be considered as minimum values.

Measurements

During the first growing season (1962), seedlings were counted weekly during the early part of the season and biweekly after both germination and mortality declined. See Lotan (1964) for complete data. Soil moisture (percent by weight) was determined at a depth of 15 cm six times during the first season. Survival following the fifth growing season was determined in October 1966 by the same procedure as in 1962.

RESULTS AND DISCUSSION

Highest fifth-year seed:seedling ratios were on the *Pinus contorta/Purshia tridentata* (Pico/Putr) habitat type, followed by *Pseudotsuga menziesii/Calamagrostis rubescens* (Psme/Caru), and *Abies lasiocarpa/Vaccinium scoparium* (Abla/Vasc) (table 2). Assuming that soil moistures measured in 1962 were indicative of general site differences in water availability (which they probably were), seed:seedling ratios were inversely related to the moistness of the habitat (an observation which is not too surprising) (fig. 1).

Site preparation techniques that produced the best survival were those that increased available soil moisture and decreased competition. The treatment with no site preparation (check plots) had very high seed:seedling ratios in both the Pico/Putr and Psme/Caru types. Based on 1 year's soil moisture measurements, the former is very

Table 2.--*Seed:seedling ratios at the end of the first and fifth growing seasons, by seedbed treatment and habitat type (* No surviving seedlings)*

Seedbed treatment	Habitat type								
	Pinus contorta/ Purshia tridentata			*Abies lasiocarpa/ Vaccinium scoparium*			*Pseudotsuga menziesii/ Calamagrostis rubescens*		
	GROWING SEASON			GROWING SEASON			GROWING SEASON		
	First	Fifth	% Surv. Years 1-5	First	Fifth	% Surv. Years 1-5	First	Fifth	% Surv. Years 1-5
Check	367:1	*∞	0	733:1	512:1	143	132:1	7,333:1	2
Burned	150:1	733:1	20	550:1	468:1	118	440:1	7,333:1	6
Disked	267:1	∞	0	49:1	81:1	60	81:1	265:1	31
Scalped	195:1	957:1	20	147:1	154:1	95	29:1	85:1	34
Trenched	33:1	550:1	6	22:1	49:1	45	28:1	512:1	5
Brushblade	112:1	1,692:1	7	28:1	54:1	52	22:1	63:1	35
Sprayed	129:1	512:1	25	42:1	63:1	67	32:1	53:1	60
Furrowed	46:1	550:1	8	19:1	31:1	61	27:1	147:1	18
Cultivated	101:1	301:1	34	21:1	33:1	64	30:1	56:1	54

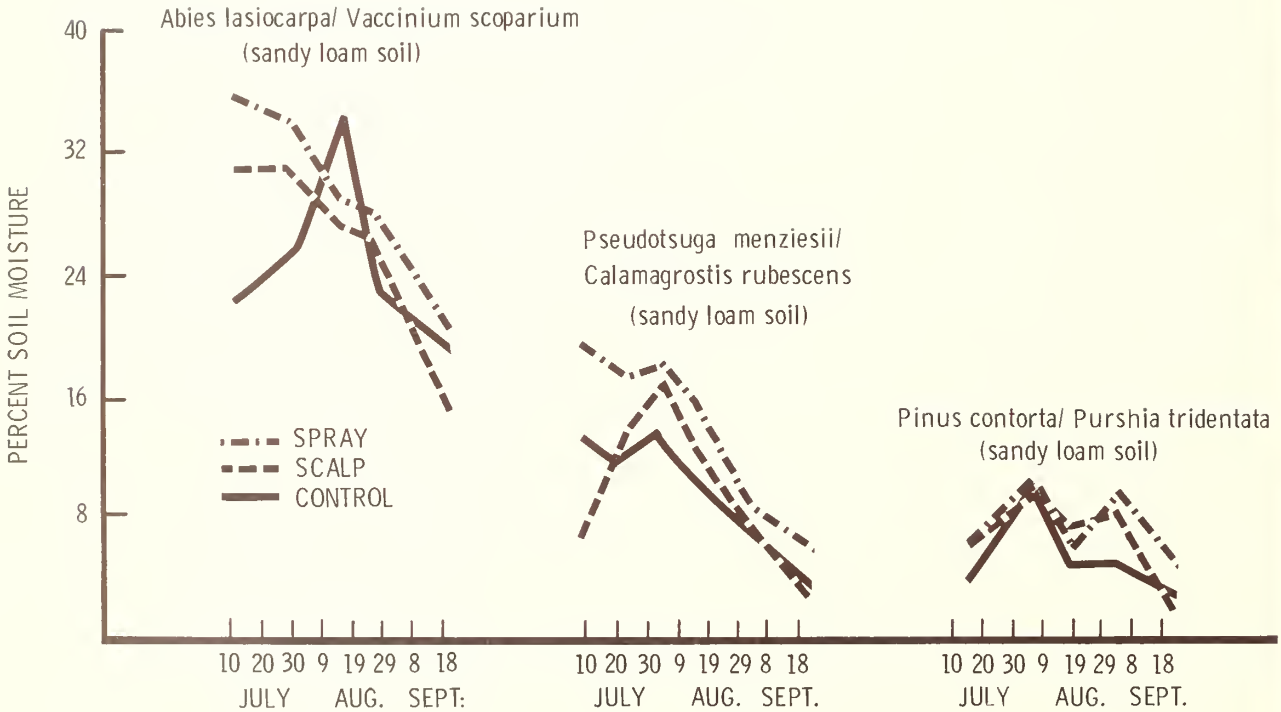

Figure 1.--Percent soil moisture at 15 cm depth for representative seedbed treatments on three habitat types, 1962.

droughty (fig. 1), and the latter, though relatively moist, is likely to have severe competition on unprepared seedbeds. On the most favorable site (Abla/Vasc), seed: seedling ratios on unprepared seedbeds were high, but still low enough to provide an acceptable stand of seedlings if available viable seed run as high as 2,500,000/ha (1,000,000/acre). This latter figure is not unreasonable in lodgepole pine stands where a majority of trees bear serotinous cones. See Lotan and Jensen (1970) for methods of computing available seed. Where overstocking has been a problem in lodgepole pine, little or no site preparation may be a useful control technique.

With the exception of the Abla/Vasc type, seed:seedling ratios after the fifth season are very much higher than after the first. Our data do not allow a determination of the point at which mortality stabilizes. However, managers should be extremely cautious about projecting ultimate stand stocking levels from survival data taken during the first few years of seedling establishment. (The decrease in seed:seedling ratio from the first to the fifth growing season on check plots and burned plots in the Abla/Vasc type is likely due to seedlings that emerged after the first-year measurements.) As a rough guide, the percentage survival figures given in table 2 may be used to estimate future stocking levels from first-year seedling counts.

Three thousand trees per hectare (1,200 per acre) at 5 years of age is a desirable stocking goal (Cole, D. M., personal oral communication). This is approximately three times greater than the optimum number of well-spaced trees, but is necessary to achieve uniform stocking. (With the site uniformly covered, thinning can be used to optimize spacing.) Seed required to produce this stocking level is given in table 3.

Table 3.--*Viable seed required to produce 3,000 trees per ha (1,200 per acre) at 5 years of age (*No surviving seedlings)*

Seedbed treatment	Habitat Type		
	Pinus contorta/ Purshia tridentata	*Abies lasiocarpa/ Vaccinium scoparium*	*Pseudotsuga menziesii/ Calamagrostis rubescens*
	Seed/ha (acre)		
Check	*∞	1,537,000 (615,000)	22,000,000 (8,800,000)
Burn	2,200,000 (880,000)	1,400,000 (560,000)	22,000,000 (8,800,000)
Disked	∞	238,000 (95,000)	800,000 (320,000)
Scalped	2,375,000 (1,150,000)	462,000 (185,000)	250,000 (100,000)
Trenched	1,650,000 (660,000)	150,000 (60,000)	1,537,000 (615,000)
Brushblade	5,000,000 (2,000,000)	162,000 (65,000)	188,000 (75,000)
Sprayed	1,537,000 (615,000)	188,000 (75,000)	162,000 (65,000)
Furrowed	1,650,000 (660,000)	88,000 (35,000)	438,000 (175,000)
ivated	900,000 (360,000)	100,000 (40,000)	162,000 (65,000)

These data were derived in a restricted geographic locale. In the absence of better information, they can be used to approximate what might be expected on similar habitat types elsewhere. However, the following limitations should be kept in mind:

1. The seed that we used were treated to discourage predation by rodents. Our data (unpublished) suggest that 30 to 50 percent of a seed crop may be eaten before the seed germinate. If the seed treatment was effective, seed loss will have been greatly reduced in our study, and seed:seedling ratios under natural conditions would be about twice as high as those given here. On the other hand, if the treatment wasn't effective (which it may not have been), the large amount of seed applied on a relatively small area may have resulted in greater than normal consumption by rodents. This would put our ratios higher than those occurring under natural conditions.

2. The burned plots were located where slash had been piled and burned. This generally results in severe soil alteration (Vogl and Ryder 1969) and cannot be related to lower intensity fires that occur when slash is broadcast burned.

3. Seed:seedling ratios may vary a great deal with short-term climatic changes. Our data represent a single 5-year period and reflect the weather during that 5-year period and no other. July rains during the first growing season were heavier than average, which undoubtedly reduced seedling mortality. In the second year, July rainfall was less than average. "Average" weather is rarely, if ever, experienced in nature. Variability is the normal pattern, and this variability may significantly alter seedling survival.

4. Although ease of regeneration increased with greater moisture in this study, the same trend cannot be extrapolated to all habitat types. Mesic (warm and moist) types, such as the grand fir series, which are characterized by high levels of competition, will likely be difficult to regenerate without thorough site preparation.

Remember our seed:seedling ratios are rough estimates. Because of the limitations stated above (especially 1 and 3) plus the many subtleties of a natural environment that cannot be duplicated in a controlled study, managers should not totally accept these (and all) general guidelines and should conduct regular on-the-ground surveys to check the accuracy of predictions.

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EFFECT OF GROWING SEASON ON SPROUTING OF BLUE HUCKLEBERRY

Melanie Miller[1]

ABSTRACT

Vaccinium globulare, *blue huckleberry, was clipped on five dates from May 19 to August 4. All clipping treatments caused more lateral bud release than occurred in control plants. May, June, and early July treatments caused the same amount of dormant bud release. The amount of shoot growth from released buds corresponded to the amount of growing season remaining after treatment. Irregularity between plants in shoot development after the July 8 treatment and the lack of bud development after the August 4 treatment are attributed to the onset of seasonal bud dormancy.*

KEYWORDS: shrub response, fire effects, larch/Douglas-fir forest

Vaccinium globulare Rydb., blue huckleberry, reproduces vegetatively after fire. Normally, growth substances manufactured in the upper part of the plant inhibit the development of buds on lower stems and rhizomes (underground stems). Death of the plant top allows these buds to elongate into shoots. Energy comes from carbohydrate stored in rhizomes.

The number of *Vaccinium globulare* sprouts after spring and fall understory burns in a larch-fir forest type was closely related to fuels, fire characteristics, and forest floor moisture (Miller 1977). The ability of *Vaccinium* to produce new shoots did not seem to vary between spring or fall fire treatments or among any of the spring treatments, although seasonal fluctuations in sprouting potential are common in many other woody species (Berg and Plumb 1972). A clipping study was carried out to test this apparent lack of variation in sprouting ability, because any fluctuation would be an important consideration in prescribed fire planning for *Vaccinium* management.

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[1] Melanie Miller is a resource management planner with the Provincial Parks Division of Alberta Recreation, Parks, and Wildlife, located in Edmonton, Alberta, Canada. She conducted the research reported here while working as a forestry technician for the Fire in Multiple Use Management Research, Development, and Applications Program at the Northern Forest Fire Laboratory, Missoula, Montana.

LITERATURE REVIEW

Fields of *Vaccinium angustifolium,* eastern lowbush blueberry, are periodically pruned with fire to increase commercial blueberry yields. The morphology and observed sprouting behavior of *V. globulare* resembles that documented for *V. angustifolium.* The physiological processes controlling plant growth stages and responses to pruning are probably similar.

V. angustifolium plants pruned with fire after July 1 did not produce sprouts until the following spring. The number of sprouts that appeared approximated that following spring or fall burns when plants were dormant (Eaton and White 1960).

Barker and Collins (1963) planted deleafed cuttings of *V. angustifolium.* Dormant buds on plants collected before July 1 grew into vegetative shoots. Plants collected in late July and early August showed irregular growth patterns.

Trevett (1962) observed that some lateral buds of *V. angustifolium* grow out after the late June or early July death of the terminal bud. Nitrogen application within 2 weeks of terminal bud death increased the amount of branching. Subsequent applications had no effect because buds had become dormant and could not respond.

STUDY AREA AND TREATMENT

The study area is located northeast of Missoula, Montana, in a western larch/Douglas-fir forest type, on a north aspect. *Vaccinium globulare* is the understory dominant, with occasional spiraea, (*Spiraea betulifolia* (Pall.) var. *lucida* Dougl.), snowberry, (*Symphoricarpos albus* (L.) Blake), and *Rosa* species.

In early May of 1975, five clones of *V. globulare* were selected for homogeneity of *Vaccinium* density, slope, and aspect. All were located within forest openings (fig. 1). Six treatment plots were placed within each clone, at least 2 meters distant from each other. Plots were randomly selected for treatment.

Figure 1.--Representative clone of Vaccinium globulare, *within which six sampling plots were located.*

Figure 2.--Sample plot after clipping. Plastic markers locate the clipped stems that were observed for lateral bud development and shoot growth.

A treatment consisted of clipping all shrub and herbaceous vegetation from a 1-m^2 plot within each of the five clones (fig. 2). Six *Vaccinium* stems nearest the center of each plot with diameters between 0.15 and 0.35 cm were marked for observation, a total of 30 plants per treatment. (Average *V. globulare* stem diameter is 0.25 cm (Brown 1976).) Any developing buds were removed from *Vaccinium* stubs after clipping. Table 1 lists clipping dates and plant phenological state at the time of clipping. Thirty control plants were also marked, and the number of elongated buds noted.

Plants were examined for stored carbohydrate. Stems and about 70 cm of attached rhizome were collected in early June, a time when plant growth requirements should have caused some depletion in carbohydrate reserves, and again in early July. Plants were brought to the lab, and thin sections taken at 10 cm intervals, beginning at the base of the first leafy shoots. The sections were stained and examined with a binocular microscope for starch grain presence.

On September 28, a 10 cm long stem-rhizome section was cut from each clipped and unclipped control plant. The number of shoots was counted, and the length of each shoot measured to the nearest millimeter from the stem base to the shoot tip.

Table 1.--*Clipping dates and plant growth stage*

Date	Growth stage
May 19, 1975	Initial leaf expansion; flower buds well developed.
June 1, 1975	Leaves 1/3 full size; flowers opening; branches elongating.
June 15, 1975	Leaves full size; flowering completed.
July 8, 1975	Berries 1/3 to 1/2 full size.
August 4, 1975	Berries ripe or almost ripe.

DATA ANALYSIS

Bartlett's test for homogeneity of variance was used to test sample variances. Analysis of variance was used to determine whether there were differences in the average number of new shoots per plant and the average amount of shoot growth on each plant. Anova tests were made for differences between clipping treatments and the control, and for interaction between treatments and the clones of shrubs, using an error term adjusted for the zero variance in two control plots. When significant differences were found, the Student-Newman-Keuls test (Sokal and Rohlf 1969) was used to make comparisons between individual mean values. Natural log values were used for analysis of variance and the Student-Newman-Keuls test for amount of shoot growth because sample variances were not homogeneous.

RESULTS AND DISCUSSION

The rhizome sections collected in early June had abundant starch grains, despite the high energy requirements of leaf expansion, flower development, and shoot elongation. Comparable amounts of starch were also present in rhizomes gathered in early July. Considering the amount of stored energy available to these *Vaccinium* plants, it seems unlikely that carbohydrate supplies limited plant growth after any of the clipping treatments.

Buds usually began to swell within a few weeks of stem clipping. Buds that developed were always those nearest the point of stem removal. The rate of bud elongation into shoots varied (fig. 3, 4, and 5).

Figure 3.--Swelling bud during initial stages of shoot elongation.

Figure 4.--Initial shoot development. Growth rates varied among plants clipped at the same time, as well as among shoots on the same stem.

Figure 5.--Shoot development 5 weeks after a May 19 clipping.

Analysis of variance found no interactions between clones and clipping dates. Any environmental and genetic differences between clones did not significantly affect *Vaccinium* sprouting. Significant differences (0.001 level) did occur between clipping treatments and control in both the number of lateral buds stimulated to develop into shoots and total shoot growth per plant (tables 2, 3).

Data for the average number of new shoots per plant and average shoot growth (mm) per plant for each clipping treatment are listed in table 4. Means followed by different letters were found to be significantly different at the 0.05 probability level by the Student-Newman-Keuls test.

There were no differences in the number of buds that began to develop after May, June, and early July clipping treatments (table 4). The May and June treatments resulted in more bud release than occurred after the August 4 treatment or in control plants, although a few shoots did develop on the unclipped plants. Additional buds may have developed on August treated plants during the subsequent growing season.

The greatest shoot growth occurred after the first clipping treatment (May 19), although statistically no greater than that following the second clipping on June 1 (table 4). The June 15 and July 8 treatments resulted in statistically less growth than the first two treatments but more than the August 4 treatment.

Table 2.--*Analysis of variance for number of buds stimulated to develop*

Source of variation	Sum of squares	Degrees of freedom	Mean square	F	Significance of F
Clipping treatment	150.844	5	30.169	18.520	0.001
Clone (block)	6.756	4	1.689	1.037	NS
Interaction (Treatment × clone)	38.044	20	1.902	1.168	NS
Error	228.000	150			
Adjusted error	228.000	140	1.629		

Table 3.--*Analysis of variance for transformed* average shoot growth per plant*

Source of variation	Sum of squares	Degrees of freedom	Mean square	F	Significance of F
Clipping treatment	468.717	5	93.743	81.022	0.001
Clone (block)	2.363	4	.591	.510	NS
Interaction (Treatment × clone)	33.447	20	1.672	1.445	NS
Error	161.969	150			
Adjusted error	161.969	140	1.157		

* $L = \ln(L + 0.5)$

Table 4.--*Treatment summaries and mean comparison tests--number of new shoots and total shoot growth per plant*

	Number of Shoots		Shoot Growth (mm)	
Date of treatment	Mean	Standard deviation	Mean	Standard deviation
5-19-75	2.97a*	1.27	92.67a	64.42
6-01-75	2.63a	1.00	59.20a	40.48
6-15-75	2.70a	1.44	19.67b	17.65
7-08-75	2.20ab	1.30	17.93b	26.45
8-04-75	1.47b	1.57	3.07cd	4.23
Control	.30c	.75	2.43d	9.19

* Treatment means followed by different letters are significantly different at the 0.05 probability level.

The standard deviation of shoot growth from released buds following the July 8 treatment (table 4) was much greater than after previous treatments, reflecting an increasing irregularity in individual plant response to clipping. The release of buds treated August 4 and lack of subsequent elongation into shoots does resemble the response of eastern lowbush blueberry to pruning. Because carbohydrate reserves seemed adequate in *Vaccinium globulare* even at a time of high growth rates, it is likely that development of bud dormancy in an increasing proportion of plants caused the decreased bud release and shoot elongation that occurred later in the growing season.

Shoot growth following pruning with fire would probably be much greater than growth following hand clipping. Smith and Hilton (1971) found no differences in bud initiation between clipping and burning treatments of *V. angustifolium*. However, dry matter production was much higher after burning. They attributed differences to the effect of nutrients released in ash and favorable microclimatic changes.

Miller (1977) stated that a spring fire would increase the density of *V. globulare* if fine fuels are dry enough to carry fire, and duff and soil wet enough to protect rhizomes. Conditions may be too wet to carry fire early in the season when plant growth potential is greatest. If later fires cause sufficient nutrient release to promote additional shoot growth, some compensation may be made for reduced *Vaccinium* growth potential.

SUMMARY AND CONCLUSIONS

A clipping study was conducted to test the hypothesis that sprouting of *V. globulare* after prescribed fire was not affected by seasonal variations in sprouting potential. There was no difference in the ability of *V. globulare* to initiate new shoots after clipping during the most active part of the growing season. The number of new shoots was the same after all clipping treatments made prior to August 4. Shoot growth that occurred after the first three clipping treatments was related to the amount of growing season remaining after treatment. Decrease in average shoot growth after the July 8 treatment was caused by limited growth in some plants, although others grew as much as those clipped earlier in the growing season. Buds on plants clipped August 4 were released, but very little shoot growth followed. The development of lateral bud dormancy probably affected bud release and shoot elongation after the July 8 and August 4 treatment. No change in growth was observed that could be related to expected high carbohydrate demands during early parts of the growing season. Plant growth stage apparently does not affect the number of shoots produced after prescribed fire removes aboveground plant parts.

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VARIATION IN SUCKERING CAPACITY AMONG AND WITHIN LATERAL ROOTS OF AN ASPEN CLONE

George A. Schier[1]

ABSTRACT

*Excised roots were used to determine variation in suckering capacity among and within lateral roots of an aspen (*Populus tremuloides *Michx.) clone. Differences among lateral roots were significant. Within segments of a lateral root sucker production showed a high degree of polarity, increasing from the distal to proximal ends. There was no evidence of a gradient in suckering capacity in a segmented root; i.e., distal segments were not significantly different from proximal ones. This indicated that aging was not a factor regulating suckering within lateral roots. Sucker production was not affected by root length.*

KEYWORDS: *Populus tremuloides*, aspen, root suckers, adventitious shoots, polarity.

Many investigators have found large interclonal differences in the relative capacity of aspen (*Populus tremuloides* Michx.) to produce root suckers (Farmer 1962; Maini 1967; Schier 1974; Steneker 1972; Tew 1970; Zufa 1971). However, only Steneker (1972) has studied intraclonal variation in sucker production. When he propagated suckers from root cuttings collected from various parts of a clone, he found significant differences in numbers of suckers produced by the ramets. He also observed a large variation in numbers of suckers produced on cuttings from the same ramet and from the same lateral root.

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My objective was to examine within-clone variation in sucker production to determine (1) if there are significant differences between lateral roots in their ability to produce root suckers, and (2) if there are gradients in sucker production along lateral roots. Sucker production along a lateral root is strongly influenced by polarity (Maini 1967; Steneker and Walters 1971); that is, a larger number of suckers arise on the proximal (end toward stem) than on the distal (end toward root apex) halves of root segments. This gradient is believed to be caused by the polar movement of endogenous growth regulators. However, age-related changes may also cause polarity in roots, as they do in stems. An aging gradient may exist in roots because the first-initiated, proximal end, and chronologically oldest part of a root may be morphologically and physiologically different from its more recently formed distal end. Generally, upper portions of stems are difficult to root, while the lower portions retain the capacity to initiate roots (Heuser 1976). In a similar manner, cuttings from sections of lateral roots near the stem may produce more suckers than cuttings from sections near the root apex.

METHODS

In the summer of 1975, roots were excavated from an area of approximately 0.1 ha within a single aspen clone in the Wasatch Mountains on the Cache National Forest east of Logan, Utah. Single root sections of varying lengths and about 1 to 2 cm in diameter were excised from 27 different lateral roots. Portions of the root sections free of defects (cankers, scars, decay, etc.) were cut into 10 cm segments and washed free of soil. The proximal ends of the segments were marked and their sequence within the lateral root recorded. The segments were randomly distributed among six trays (6 by 26 by 54 cm) in which they were planted to an average depth of 1-1/2 cm in moistened vermiculite. The trays were placed in a greenhouse where the diurnal air temperature varied between 15° and 25° C, and were watered lightly each day. After 6 weeks, the cuttings were removed from the trays and the number of suckers exceeding 5 mm in length on the proximal and distal half of each root segment recorded. The height of the tallest sucker on each segment was measured.

In the summer of 1976, a second root collection was from a different area within the same aspen clone. This time single root sections 50 cm in length and 1 to 2 cm in diameter, and free of defects, were severed from 60 different lateral roots. These were randomly divided into three groups of 20 sections each and each group given one of the following treatments: (1) uncut (1 × 50 cm); (2) cut into two 25-cm segments (2 by 25 cm); and (3) cut into five 10-cm segments (5 × 10 cm). Two sections (proximal ends marked) from each treatment were planted in each of 10 trays. The segments from cut sections were arranged in the sequence in which they were cut. Root sections were cultivated by the same procedures as before. Six weeks after planting the number and dry weight of suckers exceeding 5 mm in height were determined.

Differences in sucker production caused by either treatment or origin were tested by analysis of variance. Significance of differences between ranked means was determined by Keuls' method (Snedecor 1956). A square root transformation was applied to sucker numbers prior to analysis.

RESULTS

Long Root Sections

The length of the lateral root sections excavated ranged from 51 to 412 cm (mean, 182 cm). Diameters of the defect-free root segments (10 cm), cut from the root sections, ranged from 8 to 24 mm (mean, 16.2 mm). There was not much taper within the long rope-like lateral roots. The mean difference in diameter between the largest and smallest segments within a lateral root was only 4.4 mm.

Table 1.--*Variation among lateral roots within an aspen clone in the mean number of suckers per segment (10 cm) and mean height of tallest suckers per segment*

Lateral root	Suckers per segment	Height of tallest sucker	Lateral root	Suckers per segment	Height of tallest sucker
		mm			*mm*
1	6.3	38	15	6.1	42
2	3.7	48	16	4.8	37
3	11.6	51	17	8.3	42
4	8.6	41	18	11.6	51
5	7.8	45	19	0.8	17
6	4.0	35	20	9.6	45
7	11.2	41	21	0.6	12
8	13.0	42	22	7.8	38
9	10.2	30	23	10.7	51
10	17.2	40	24	3.4	48
11	15.9	49	25	12.3	35
12	4.9	42	26	6.8	49
13	5.2	43	27	22.7	44
14	4.1	37			
			MEAN	8.56	42.0

The difference among lateral roots in both number and height of suckers (table 1) was highly significant (1 percent level). Suckering was not related to root diameter. A "t" test for paired replicates showed that the proximal half of root segments produced significantly more suckers than the distal halves. Sixty-four percent of all suckers arose from the proximal ends and only 36 percent from the distal ends. There was no evidence of a gradient in suckering capacity along the lengths of lateral roots. Mean number of suckers produced from segments in the proximal and distal halves of root sections were: proximal, 8.36; distal, 8.75. One would expect less variation in suckering capacity between adjacent segments than between distant segments, but this was not found.

Effect of Root Length

Effect of root length on number and dry weight of suckers produced was as follows:

Treatment	*Suckers per section*	*Dry weight per sucker*
		(mg)
1 × 50 cm	51.0	14.4
2 × 25 cm	55.9	12.9
5 × 10 cm	39.7	13.9

Cutting 50-cm lateral root sections into segments (10 or 25 cm) did not significantly affect number or dry weight of suckers produced by the sections. Within each of the three treatments (1 × 50 cm, 2 × 25 cm, or 5 × 10 cm), differences among lateral

Table 2.--*Distribution of suckers along 50-cm sections of cut and uncut aspen roots (proximal end at 0, distal end at 50 cm)*

Sample condition	2 × 25 cm			5 × 10 cm					
	0	25	50	0	10	20	30	40	50
	Percent								
Uncut	74.8	25.2		[1]33.5	29.8	19.8	12.2	4.7	
Cut	53.2	46.8		21.8	19.5	18.5	18.8	21.4	

[1]Underlined percentages are not significantly different from each other.

root sections were highly significant (1 percent level). Sucker numbers did not differ significantly between proximal and distal root segments (table 2). However, within uncut sections there was a distinct gradient in suckering capacity; the number of suckers increased along the root from the distal to the proximal end.

DISCUSSION

Steneker and Walters (1971) also found that length of root cuttings usually did not significantly affect sucker production. However, they found that cutting 36-inch (91.4-cm) root sections into 6-inch (15.2-cm) segments significantly reduced mean sucker heights. They also found more suckers on the proximal three segments than on the distal three segments of cut 36-inch root sections, although polarity was not as evident as in uncut roots.

The polarity of sucker formation on excised aspen roots appears to be caused by physiological factors unrelated to aging. If aging had affected suckering, then gradients in suckering capacity would have occurred along segmented lateral roots. Polarity in roots is usually attributed to the transport of auxin toward root tips (Batra and others 1975; Robinson and Schwabe 1977). Auxin, which suppresses suckering in roots of intact plants, breaks down after the roots are excised (Eliasson 1971; Schier 1973c, 1975). Suckers are then able to develop. Polar movement of the residual auxin in segments probably causes higher concentrations in the distal than in the proximal halves, so the distal halves produce fewer suckers. Cytokinins, which stimulate shoot formation, may also influence the polarity shown in sucker development because these hormones move in a proximal direction (El-Saidi 1971; Wareing and Phillips 1970).

Most suckers that arise on aspen roots appear to develop from suppressed shoot primordia (Schier 1973b). Therefore, variation in the capacity of lateral roots to sucker is probably caused primarily by differences in numbers of primordia. Some roots may have many more primordia than others because they are exposed to injuries that stimulate primordia formation.

Generally, roots vary in sensitivity to stimuli that initiate primordia because of differences in hormone levels and ratios, water content, and concentration of nutrients. Two factors that may affect the physiological condition of lateral roots are microclimate and position in the clonal root system. Temperature, an important microclimatic variable, varies with soil depth and exposure to radiation. The position of a lateral root in the root system will determine its location with respect to ramets of various ages and vigor. This will determine the quantity of carbohydrates and auxins and other growth translocated to the root. Some clones have roots with few primordia; a major portion of the suckers are initiated after excision (Schier 1973a). Root cuttings from these clones are probably physiologically preconditioned for sucker development by the factors mentioned. Early growth of suckers may vary with concentration of carbohydrate reserves (Schier and Zasada 1973).

Any sampling method used to estimate suckering capacity of aspen clones must take into consideration the large within-clone variation in sucker production. A procedure that I have found to work well is to collect single cuttings from 30 or more locations within a clone. Using this procedure I have found significant differences in suckering capacities among clones (Schier 1974).

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ESTIMATING PINYON-JUNIPER CORDWOOD WITH THE LINE-INTERSECT METHOD

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ABSTRACT

*Adapts the line intersect method, developed for inventorying logging wastes, to estimating cordwood in singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*). Reviews mathematical basis and provides a field application.*

KEYWORDS: pinyon, juniper, line intersect, cruising, Nevada

Line-intersect sampling resembles the better-known line-intercept method, but the two methods should not be confused. Line-intercept is primarily used for determining cover percentage, but line-intersect is a procedure for sampling with probability proportional to size (p.p.s.). The line-intersect technique was developed by Warren and Olsen (1964) to inventory logging residue. Brown (1971) adapted this technique to sample fuel volume and surface area. A generalized theory on line-intersect sampling is presented by Vries (1973).

The line-intersect method is particularly suited for inventorying woodland trees. It provides a relatively simple way to apply p.p.s. sampling to trees that have irregular (sometimes multiple) stems, and branches all the way to the ground. It can be used to inventory total biomass, wood volumes, fuel loading, and related parameters. In this paper, we apply the method to inventorying pinyon and juniper cordwood in Nevada and then explain how the procedure was developed.

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The sampling unit is a 100-foot line transect, laid out by compass and tape. For each tree whose crown intersects the line, tally as shown in figure 1: species, diameter at stump height (6 inches) to the nearest inch, height to the nearest even foot, and crown factor.

There is one exception to tallying all trees with crowns over the line: a tree is not tallied if the center of its root crown lies beyond the end of the transect. If the transects are laid out in a continuous series of line segments, this exception applies only to the two ends of the series. Within the series, it makes little difference which transect a borderline tree is tallied in.

1	2	3	4	5	6	7	8	9	
Transect	Species	Stump Diameter	Height	Crown Factor	Cords per Acre				Remarks
					Uncorrected	Pinyon	Juniper	Total	
1	J	15	16	1.1	1.7		1.9		
	J	8	14	1.2	.5		.6		
	P	7	14	1	.3	.3			
	P	9	16	1	.6	.6			
	P	9	18	1.1	.8	.9			
	P	8	20	1.4	.8	1.1			
	P	8	16	1.2	.5	.6			
	P	10	16	1.1	.7	.8			
						4.3	2.5	6.8	
2	P	13	22	1	2.1	2.1			
	P	12	20	1	1.5	1.5			
	P	9	18	1	.8	.8			
	P	8	16	1.2	.5	.6			
	P	9	16	1	.6	.6			
	P	11	20	1.1	1.3	1.4			
						7.0	—	7.0	
3	P	11	20	1	1.3	1.3			
	P	9	20	1.1	.9	1.0			
	P	16	20	1.2	2.5	3.0			
	P	14	26	1.2	4.8	5.8			
						11.1	—	11.1	
4	P	16	20	1.1	2.5	2.8			
	P	13	18	1.1	1.4	1.6			
	P	11	18	1	1.1	1.1			
	P	11	20	1.1	1.3	1.4			
	P	11	22	1.1	1.6	1.8			
	P	10	20	1	1.1	1.1			
						9.8	—	9.8	
5	J	22	18	1.1	4.2		4.7		19", 15"
	P	8	16	1.2	.5	.6			
	P	13	22	1.1	1.6	1.8			
	P	8	14	1	.4	.4			
						3.7	4.7	8.4	
Ave						7.2	1.4	8.6	Average

Figure 1.--Line intersect tally sheet.

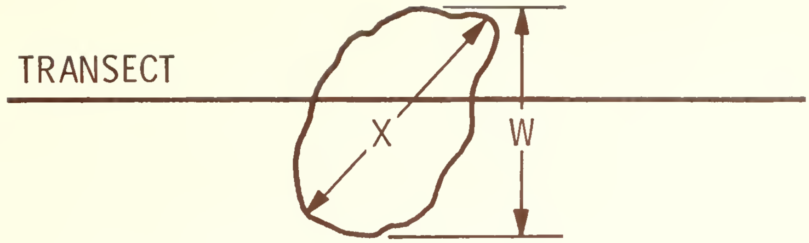

Figure 2.--Crown factor is equal to X/W, the maximum crown diameter divided by the crown spread perpendicular to the transect line. The crown factor is 1.2 in this example.

The crown factor is maximum crown diameter divided by the crown spread perpendicular to the line (fig. 2). The cruiser can estimate the crown factor, height, and stump diameter after measuring a few trees. The stump diameter is measured by diameter tape, not by calipers.

If there is more than one stem at stump height, record the diameters of each stem in the remarks column, as shown for the first juniper in transect 5 in the example (fig. 1). The equivalent diameter is determined by entering the diameters of the two largest stems as D1 and D2 on the nomogram (fig. 3). In the example, the line between 19 inches and 15 inches indicates an equivalent diameter of 22 inches.

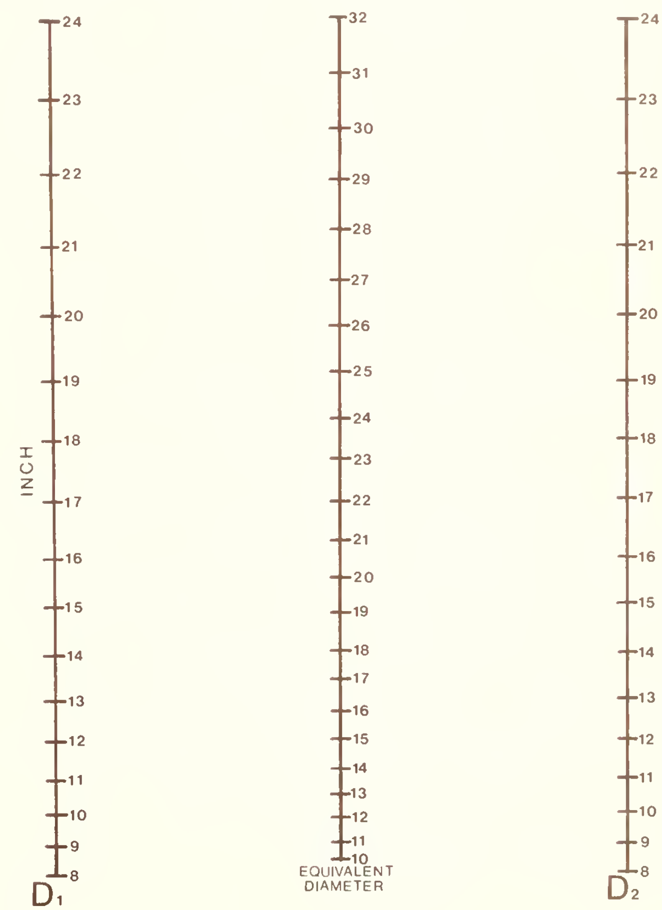

Figure 3.--Nomogram to determine equivalent diameters.

If there is more than one stem at breast height, deduct 2 inches from the actual stump diameter before tallying. This correction is built into the nomogram, so no deduction is made if the tree forks below stump height.

Cords per acre is calculated by the following steps:

1. Enter the appropriate values from tables 1 and 2 in column 6 of the tally sheet. This is the cords per acre represented by each sample tree, based on diameter, height and species.

2. Multiply the values in column 6 by the crown factors in column 5 and enter the corrected values in column 7 for pinyon or column 8 for juniper.

3. For each 100-foot transect, add up the values in columns 7 and 8 to obtain estimated cords per acre. In the example in figure 1, transect 1 has an estimated 4.3 cords per acre of pinyon and 2.5 cords per acre of juniper.

4. Average the transect estimates. In the example, estimated cords per acre is: total, 8.6; pinyon, 7.2; and juniper, 1.4.

Table 1 is based on measurements of 50 pinyons. Table 2 is based on only 26 junipers and covers a narrower range of heights. Table 1 should be used for junipers outside the range of table 2 because it will give better estimates than extrapolations of table 2.

Table 1.--Pinyon cords per acre by line intersect

Dia.	Height (feet)																		
(in.)	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	.2	.3	.4	.4	.5														
7	.2	.3	.4	.5	.6	.7	.8	.9	1.0										
8	.2	.4	.5	.6	.8	.9	1.0	1.2	1.3	1.5									
9	.2	.4	.6	.8	.9	1.1	1.3	1.5	1.7	1.8									
10		.5	.7	.9	1.1	1.3	1.6	1.8	2.0	2.2	2.5								
11		.6	.8	1.1	1.3	1.6	1.8	2.1	2.3	2.6	2.9								
12		.7	.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3								
13		.8	1.1	1.4	1.8	2.1	2.4	2.7	3.0	3.4	3.7	4.1							
14			1.3	1.6	2.0	2.3	2.7	3.0	3.4	3.8	4.1	4.5							
15			1.5	1.9	2.2	2.6	3.0	3.4	3.8	4.1	4.5	4.9							
16			1.7	2.1	2.5	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7						
17				2.4	2.8	3.2	3.6	4.1	4.5	4.9	5.3	5.8	6.2	6.6					
18				2.7	3.1	3.5	4.0	4.4	4.9	5.3	5.7	6.2	6.6	7.1					
19				3.0	3.4	3.8	4.3	4.8	5.2	5.7	6.1	6.6	7.1	7.5	8.0				
20				3.3	3.7	4.2	4.7	5.1	5.6	6.1	6.6	7.0	7.5	8.0	8.4	8.9			
21					4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.4	7.9	8.4	8.9	9.4	9.9		
22					4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	9.8	10.3	10.8	
23					4.7	5.2	5.7	6.2	6.7	7.2	7.7	8.2	8.7	9.2	9.7	10.2	10.7	11.2	11.7
24					5.1	5.6	6.1	6.6	7.1	7.6	8.1	8.6	9.1	9.6	10.2	10.7	11.2	11.7	12.2
25					5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.6	12.1	12.6
26					5.9	6.4	6.9	7.4	7.9	8.4	8.9	9.4	9.9	10.4	10.9	11.4	11.9	12.4	12.9
27					6.3	6.8	7.3	7.8	8.3	8.8	9.3	9.8	10.3	10.8	11.3	11.8	12.3	12.8	13.3
28					6.8	7.2	7.7	8.2	8.7	9.2	9.7	10.2	10.7	11.2	11.7	12.2	12.6	13.1	13.6
29					7.2	7.7	8.2	8.6	9.1	9.6	10.1	10.6	11.0	11.5	12.0	12.5	13.0	13.4	13.9
30					7.7	8.1	8.6	9.1	9.5	10.0	10.5	10.9	11.4	11.9	12.3	12.8	13.3	13.7	14.2

Table 2.--Juniper cords per acre by line intersect

Dia. (in.)	Height (ft.) 12	14	16	18	20	22	24	26	28
8	.2	.5	.7						
9	.2	.6	.8	.9					
10	.2	.6	.9	1.0					
11	.3	.7	1.0	1.2	1.2				
12	.3	.8	1.1	1.4	1.4				
13	.4	.9	1.3	1.6	1.7				
14	.5	1.1	1.5	1.8	1.9	2.0			
15	.6	1.2	1.7	2.0	2.2	2.3			
16	.8	1.4	1.9	2.3	2.5	2.6			
17	.9	1.6	2.1	2.5	2.8	3.0			
18		1.8	2.4	2.8	3.2	3.4			
19		2.0	2.6	3.1	3.5	3.7	3.8		
20		2.3	2.9	3.5	3.9	4.2	4.3		
21		2.5	3.2	3.8	4.3	4.6	4.8		
22			3.6	4.2	4.7	5.0	5.3		
23			3.9	4.6	5.1	5.5	5.8	5.9	
24			4.3	5.0	5.5	6.0	6.3	6.5	
25			4.6	5.4	6.0	6.5	6.8	7.0	
26				5.8	6.5	7.0	7.4	7.6	7.8
27				6.3	7.0	7.5	8.0	8.3	8.4
28						8.0	8.6	8.9	9.1
29						8.5	9.2	9.5	9.8
30							9.8	10.2	10.5

The number of juniper posts per acre can also be estimated by the line-intersect technique, either separately or in combination with cordwood cruising. For each juniper intersecting the line, count the number of posts in the tree and estimate the crown width perpendicular to the line (W in fig. 2). To calculate estimated posts per acre for each transect: divide the number of posts in each tree (n_i) by crown width (W_i), add up the results for the transect and multiply by 435.6.

$$\text{Posts per acre} = 435.6 \sum^{i} \frac{n_i}{W_i}$$

Pinyon Christmas trees per acre can be estimated in the same manner.

CONFIDENCE INTERVAL AND SAMPLE SIZE

Confidence limits (L) and coefficient of variation (C%) are calculated in the conventional way:

$$L = \pm\, s_{\bar{x}} t_{.05}$$

$$C\% = 100 \cdot s/\bar{x}$$

in which $\bar{x}$ is the average, s is the standard deviation, and $s_{\bar{x}}$ is the standard error of the individual transect totals. The standard equation for sample size (N) is:

$$N = \left(\frac{C\%}{E\%} \cdot t_{.05}\right)^2$$

E% is the allowable error. This equation is somewhat difficult to solve because the value of t varies with the degrees of freedom (N-1) and iterative calculations are required. The following equation overcomes this difficulty and is accurate for all values of N greater than two.

$$N = 2.4 + 3.84 \left(\frac{C\%}{E\%}\right)^2$$

For the data in the example (fig. 1):

$$L = 0.82 \times 2.776 = 2.3 \text{ cords per acre}$$

$$C\% = 100 \times 1.84/8.6 = 21.4\%$$

$$N = 2.4 + 3.84\left(\frac{21.4\%}{10\%}\right)^2 = 20$$

These results indicate that the confidence interval of the 5-transect estimate is 8.6 ± 2.3 cords per acre and that 20 transects would be needed to estimate the number of cords in this stand within 10 percent, assuming the 5 transects represent the true variation in the stand. Only 7 transects would be needed for 20 percent error.

DERIVATION OF THE PROCEDURE

The described procedure is based on a variable-width belt transect 100 feet long and "W" feet wide. The width of the transect is, in effect, equal to the crown spread of each tallied tree (W_i) perpendicular to the transect line. Consequently, the equivalent plot area (A_i) associated with each tree is directly proportional to W_i:

$$A_i = \frac{100 \cdot W_i \text{ ft}}{43{,}560 \text{ ft}^2/\text{acre}} = \frac{W_i}{435.6} \text{ acres}$$

The total volume per acre (V/A) estimated by a transect is the sum of the volumes (V_i) of the individual tallied trees divided by their respective equivalent areas (A_i).

$$V/A = \sum^{i}\left(V_i/A_i\right)$$

Substituting $\frac{W_i}{435.6}$ for A_i gives:

$$V/A = 435.6 \sum^{i}\left(V_i/W_i\right)$$

With this equation we could calculate volume per acre if we know W_i and V_i. V_i would be obtained from volume tables and W_i would be measured or estimated directly. Fortunately, we can eliminate the time-consuming determination of W_i in pinyon-juniper cruising. We have found that volume of pinyon and juniper trees is approximately proportional to maximum crown diameter (X_i) at any fixed combination of height and diameter. Consequently, V_i/X_i can be estimated on the basis of height and diameter, and can be tabulated in volume table format.

The equation can be modified to

$$V/A = 435.6 \sum^{i} \left(\frac{V_i}{X_i} \cdot \frac{X_i}{W_i} \right)$$

to eliminate the need for estimating X_i and W_i by substituting the crown factor (X_i/W_i) which can be estimated more quickly and accurately.

Values for 435.6 V_i/X_i are listed in table 1 (singleleaf pinyon) and table 2 (Utah juniper). As outlined in the procedure section, V_i/A_i is obtained by multiplying these values by crown factors.

Tables 1 and 2 are based on regression analyses of data obtained by felling, sectioning, and weighing 50 singleleaf pinyon and 26 Utah junipers on selected sites across Nevada. The equation for pinyon is:

$$\frac{M}{X} = 15.303 - 0.7894H - 3.150D + 0.1715DH + 0.1056D^2 - 0.00347D^2H$$

$$R^2 = 0.96$$

in which M is the weight (lbs) of oven-dry wood larger than 3" diameter in the tree, X is maximum crown diameter (ft), H is total height (ft), and D is diameter (in) outside bark at stump height (6 in). For trees with more than one stem larger than 3 inches diameter at breast height, D was reduced 2 inches for the analysis. For trees with two stems at stump height, D was calculated by

$$D = \left(D_1{}^2 + D_2{}^2\right)^{\frac{1}{2}} - 2$$

The nomogram in figure 3 is derived from the equation. No trees with more than two stems at stump height were sampled, but we believe that if there are more than two stems, the smaller stems would contribute little to cordwood volume.

M/X was converted to V/X by dividing by 2,300 lb/cord. This conversion factor is based on our finding about 70 cubic feet of solid wood (bark excluded) per cord and that oven-dry pinyon weights about 33 pounds per cubic foot. These values of V/X were multiplied by 435.6 and listed in table 1.

The equation for juniper is:

$$\frac{M}{X} = - 8.779 + 2.002H - 0.0793H^2 - 1.897D + 0.04230D^2 + 0.0998HD$$

$$R^2 = 0.98$$

The conversion factor for juniper is 2,100 lbs/cord, based on an estimated 30 lbs per cubic foot of ovendry wood.

The cruising procedure outlined in this paper may be refined as we acquire more data, but we believe the procedure is sound and that few changes will be necessary.

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FUEL PARTICLE DIAMETERS OF WESTERN HEMLOCK SLASH

Collin D. Bevins[1]

ABSTRACT

*Quadratic mean diameters for converting fuel particle intersection counts into volume estimates for 1-, 10-, and 100-hour moisture timelag classes were determined for western hemlock (*Tsuga heterophylla *(Raf.) Sarg.) slash particles in the Pacific Northwest.*

The planar intersect technique is commonly used to inventory small dead and down woody fuels (Brown 1971, 1974; Brown and Roussopoulos 1974). To facilitate fieldwork, particle intersections are tallied by three size classes that correspond to 1-, 10-, and 100-hour average moisture timelag classes (Fosberg 1970):

Fuel moisture time-lag (h)	*Diameter at intersection (cm)*
1	0.0 - 0.6
10	0.6 - 2.4
100	2.5 - 7.6

The National Fire-Danger Rating System recognizes these same fuel moisture timelag classes (Deeming and others 1977).

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In sampling small dead and down woody fuel, a fuel particle is assigned to a size class on the basis of its diameter at the point of intersection with the sampling plane. To convert fuel intersection counts into volume and load estimates, it is necessary to know the quadratic mean diameters of the fuel species present within each timelag class. Brown (1974) and Brown and Roussopoulos (1974) presented quadratic and arithmetic mean diameters of several species common to the western and midwestern United States (table 1). However, data on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were not available. Western hemlock quadratic and arithmetic mean diameters suitable for use in estimating the species' volume are presented here.

Table 1.--*Slash fuel particle diameters of western hemlock and other common species*[1]

Timelag (h)	Species[2]	Number of observations	Quadratic mean diameter	Average diameter	Standard deviation
			- - - - - - - - - -	cm	- - - - - - - - - -
1	WH	1,692	0.21	0.14	0.15
	DF,GF,C,S	1,071	.28	.26	.10
	L	188	.31	.29	.10
	JP	138	.32	.29	.10
	O	358	.37	.34	.14
	LP	192	.40	.34	.10
	RP	181	.45	.43	.12
10	RP,O	455	1.25	1.15	.47
	JP	29	1.31	1.19	.56
	DF,GF,LP,L,S	1,273	1.34	1.24	.49
	PP,C	551	1.43	1.35	.46
	WH	386	1.55	1.43	.59
100	L,C,S	313	3.85	3.70	1.06
	RP	13	4.03	3.86	1.20
	DF,PP,GF	587	4.27	4.08	1.27
	JP	72	4.55	4.30	1.49
	WH	261	4.63	4.43	1.37
	LP	169	4.75	4.51	1.50

[1]Data for species other than western hemlock are taken from Brown and Roussopoulos (1974)

[2]The following species abbreviations are used:

C Western redcedar *Thuja plicata* Donn
DF Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco
GF Grand fir *Abies grandis* (Dougl.) Lindl.
JP Jack pine *Pinus banksiana* Lamb.
L Western larch *Larix occidentalis* Nutt.
LP Lodgepole pine *Pinus contorta* Dougl.
O Oak *Quercus spp.*
PP Ponderosa pine *Pinus ponderosa* Laws.
RP Red pine *Pinus resinosa* Ait.
S Engelmann spruce *Picea engelmannii* Parry
WH Western hemlock *Tsuga heterophylla* (Raf.) Sarg.

Measurements of western hemlock diameters were taken in fresh and 1-year-old clear-cut slash at three locations in the Pacific Northwest: the Soleduck Ranger District of the Olympic National Forest, and the North Bend and Skykomish Ranger Districts of the Mt. Baker National Forest.

A sample transect was randomly located across each of the three slash areas. The diameter of each western hemlock fuel particle intersecting the transect was measured at the point of intersection. Particle diameters were measured with a caliper graduated to 0.1 millimeter.

The sample size of each timelag class and the resulting quadratic and arithmetic mean diameters are presented in table 1. The slash fuel particle diameters of other common species, taken from Brown and Roussopoulos (1974), are also presented for comparison. Western hemlock appears to have a lower quadratic mean diameter in the 1-hour timelag size class than any of the other species measured. The 10-hour diameter of western hemlock, however, is larger than any of the other species. This reflects the fine branching habit of western hemlock, which has many small terminal twigs supported by a single branch. Similarly, the quadratic mean diameter of the 100-hour timelag class is slightly larger than those of most other species presented in table 1.

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TERPENES FOR INDIRECT SELECTION OF GROWTH POTENTIAL IN ROCKY MOUNTAIN DOUGLAS-FIR

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ABSTRACT

Possibilities of using terpene composition for indirect selection of growth potential were explored for Rocky Mountain Douglas-fir. Volatile leaf oil analyses were made on 170 5-year-old seedlings that represented full-sib hybrid families, wind-pollinated parental lines of inland origin, and wind-pollinated parental lines of coastal origin. Correlation analyses showed that terpenes could not be used efficiently for indirect selection of growth potential in the inland variety. But, terpenes may be useful in selecting parental lines in programs of intervarietal hybridization.

KEYWORDS: *Pseudotsuga menziesii*, terpenes, indirect selection, growth potential

Because tree growth is a product of genotype and environment, the genotype of a tree is often poorly expressed phenotypically. In many instances it would be desirable to identify trees of superior growth potential from morphological, physiological, or biochemical traits that are not under strong environmental influence. Such indirect selection would facilitate rapid incorporation of genetics research into management options. For example, seed orchards could be stocked without progeny tests, and trees from which natural regeneration is to be encouraged could be identified readily.

Unique possibilities for indirect selection of growth potential exist in the inland variety of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in northern Idaho. First, the inland variety and the coastal variety (*P. menziesii* var. *menziesii*) are readily classified according to the terpenes contained within volatile leaf oils (von Rudloff 1972). Terpene concentrations have proven so useful diagnostically that von Rudloff (1973a, 1973b) recognized three coastal types; a single inland type; and three types that bridge the varieties: intermediate, coastal intermediate, and interior intermediate. Moreover, trees that express varying degrees of intermediacy in terpene

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omposition are occasionally found in inland populations (von Rudloff 1973b). Since nvironmental conditions have little effect on terpenes (von Rudloff 1972), these nland trees of intermediate terpene composition presumably contain genes for terpene roduction that are of coastal origin.

Secondly, it is well known that the growth potential of the coastal variety is uperior to that of the inland variety. Yet, northern Idaho populations are from an rea that represents a floristic transition from the maritime coastal forests to Rocky lountain forests (Daubenmire and Daubenmire 1968). The growth potential of populations from northern Idaho is generally superior to that of western Montana populations (Rehfeldt 1974). This difference in growth potential may reflect a higher frequency of genes typical of the coastal variety in populations from northern Idaho than in those from Montana.

Thus, possibilities of using terpenes for indirect selection of growth potential arise from concomitant variation in both traits. Can individual trees of the inland variety in northern Idaho be selected for high growth potential according to the relative concentration of those terpenes that typify the coastal variety? Although Hanover and Furniss (1966) found no relationship between the growth of 94 Douglas-fir trees and concentrations of four terpenes, the populations they sampled were from central Idaho and west-central Montana--geographical areas that are far removed from current zones of introgression between the two varieties.

If terpenes are usable for indirect selection of growth potential, terpene composition and rate of growth must be interdependent. This will happen only if terpenes and growth rate are (1) pleiotropic or (2) not at linkage equilibrium. Pleiotropic effects, the expression of dissimilar traits from the same genetic mechanism, require that the traits be correlated nearly perfectly. Linkage occurs between genes located on the same chromosome. At linkage equilibrium, the occurrence of genes at linked loci is independent. Equilibrium between linked genes is approached slowly (the average number of generations to reach equilibrium = reciprocal of the recombination frequency). Thus, even though introgression between the two varieties may have progressed for many generations, closely linked genes may not have reached equilibrium.

METHODS

Leaf oil analyses were made on 170 5-year-old seedlings growing in northern Idaho. These seedlings had been included in tests of intervarietal hybridization and represented 10 families: 4 full-sib hybrid families; 4 wind-pollinated parental lines of inland origin; and 2 wind-pollinated parental lines of coastal origin (table 1). The cultural conditions under which the seedlings were raised and the nursery performance of hybrids and parental lines are documented elsewhere (Rehfeldt 1977). The height of all seedlings was measured at age 4. One year later, leaves were collected for analyses of leaf oils.

After dipping into liquid nitrogen, frozen leaves were stripped from the branches and stems. Leaves were steam-distilled for 5 h and the volatile oil was recovered as described by von Rudloff (1972). Aliquots (0.5 to 1.0 μl) of the volatile oil obtained from each seedling were analyzed on four different gas-liquid chromatographic (g.l.c.) columns (von Rudloff 1976a). The relative percentages of each terpene were determined by area integration of the g.l.c. peaks (sum of all peaks for each sample = 100 percent) with a Hewlett-Packard model 3352 data system. Results from the four columns were averaged. The g.l.c. error was 0.1 to 0.2 percent for well-resolved peaks and 0.3 to 1.0 percent for overlapping ones (see also von Rudloff 1973a). Peak identities had been established previously.

Table 1.--*Origin of families and average terpene classification of progenies. Classifications are based on techniques developed by von Rudloff (1972)*

Family code	♀ parent	♂ parent	General terpene classification of progenies	Number of seedlings
0	[1] 7	wind	interior intermediate	16
1	[1] 16	wind	interior	17
2	[1] 19	wind	interior	17
3	[1] 25	wind	interior	16
4	7	98	coastal intermediate	20
5	19	98	interior intermediate	16
6	16	100	interior intermediate	19
7	25	100	intermediate	20
8	[2] 98	wind	coastal	16
9	[2] 100	wind	coastal	13

[1] Identification number of parent tree growing near Clarkia, Idaho.
[2] Identification number of parent tree growing near Lake Cowichan, B.C. The authors gratefully acknowledge the assistance of A. Orr-Ewing and J. C. Heman, British Columbia Forest Service, Victoria, B.C.

The terpene compositions of individual seedlings and families were compared according to groups of biogenetically related terpenes (von Rudloff 1976b) that are defined in table 2. These comparisons were based on principles established previously (von Rudloff 1972, 1976b): seedlings having terpene compositions typical of the coastal variety have high levels of β-pinene, the sabinenes, and the terpinenes; seedlings having high levels of limonene and the camphene group are typical of the inland variety. Finally, the term "flavor" is used to describe terpene compositions that vary in the direction of those patterns that typify either variety.

Simple linear correlation coefficients were calculated between seedling height and the relative percentage of each terpene. Because of heterogeneous variances and skewed frequency distributions, height measurements were transformed to logarithms and percentages were transformed to $\sqrt{\chi + 1/2}$ before calculating correlation coefficients (Steel and Torrie 1960). Associations between terpenes and growth rate were interpreted according to effects of either pleiotropism or linkage.

Table 2.--*Family means for height (cm) and concentrations (percent) of terpenes summed according to groups of biogenetically related terpenes (von Rudloff 1976b)*

Family	α-pinene	β-pinene	Sabinene group[1]	Terpinene group[2]	Camphene group[3]	Citronellol group[4]	Limonene	Height
	Percent							*Cm*
Inland								
7 x wind	12.0	7.2	1.5	2.0	57.1	7.2	4.5	41.7
16 x wind	11.5	3.3	0.1	1.3	63.8	5.6	4.8	46.3
19 x wind	11.6	3.8	0.2	1.3	66.1	4.8	5.1	40.0
25 x wind	11.7	4.6	0.5	1.6	59.8	9.6	4.2	32.1
Hybrid								
7 x 98	14.2	39.0	5.7	4.2	17.7	7.7	1.9	82.6
19 x 98	12.5	12.5	0.8	1.5	55.1	6.3	4.1	45.2
16 x 100	12.8	10.1	0.6	1.3	53.4	8.2	4.3	59.7
25 x 100	12.1	16.0	1.3	1.9	41.4	14.6	3.5	66.6
Coastal								
98 x wind	14.3	55.2	1.3	1.7	1.2	14.3	1.2	62.1
100 x wind	13.5	49.3	1.2	1.7	1.0	18.5	1.6	66.8

(Precursor group spans α-pinene through Limonene.)

[1] α-thujene + sabinene
[2] α- and γ-terpinene + terpinolene + terpinen-4-ol
[3] santene + tricyclene + camphene + borneol + bornyl acetate
[4] linalool + citronellol + citronellyl acetate + geranyl acetate

RESULTS AND DISCUSSION

The results of terpene analyses were unexpected. These results are expressed as an average terpene composition for each family (table 1) according to techniques of classification developed by von Rudloff (1972). In general, all wind-pollinated progenies of coastal origin (families 8 and 9, table 1) exhibited terpene compositions that are typical for coastal British Columbia. However, the wind-pollinated progenies of only two inland trees (families 1 and 2) expressed terpene compositions that were typical of the interior variety. A few wind-pollinated progenies of tree 25 (family 3) had terpene compositions of slight coastal flavor, but those of tree 7 (family 0) were extremely variable.

In fact, classification of terpenes of individual seedlings within wind-pollinated offspring of tree 7 revealed typical interior patterns, interior intermediate patterns, and even intermediate patterns. Mean values (table 2) show that an average wind-pollinated progeny of tree 7 had higher levels of β-pinene, the sabinenes, and the terpinenes, and lower levels of limonene and the camphenes than progenies of the other three interior trees. Consequently, it appears that tree 7 and perhaps tree 25 are segregating for genes controlling terpenes typical of the coastal variety.

The degree of coastal flavor to the classification of terpenes in families of hybrid origin follows patterns expected from the classification of parental lines (tables 1 and 2). However, classifications of all hybrid progenies show a greater interior flavor than that expected from an average of parental classifications.

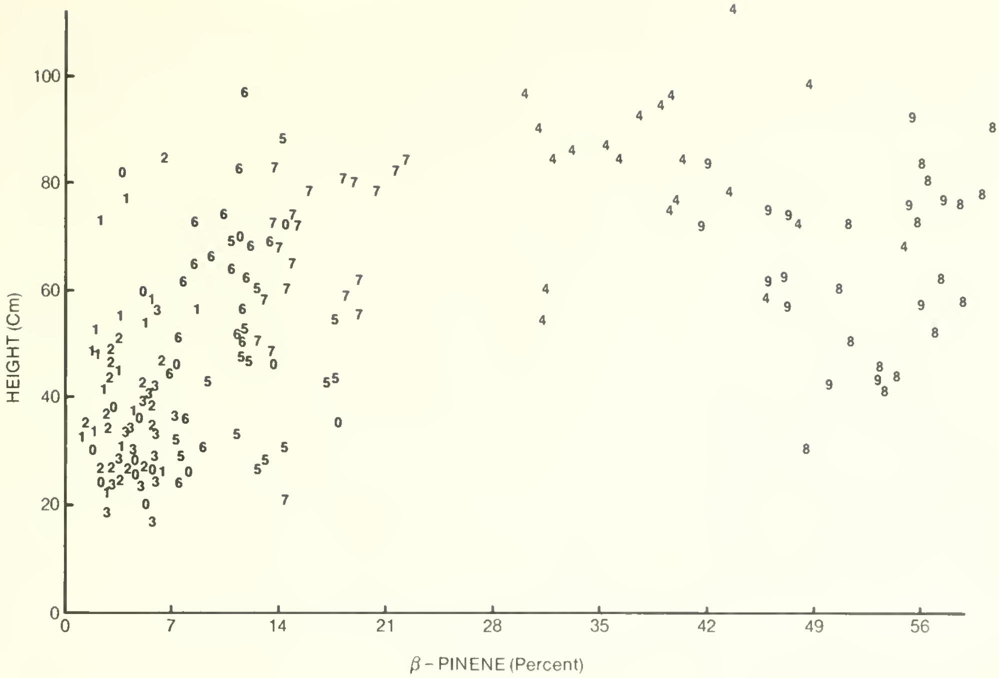

Figure 1.--Relationship between the height of individual seedlings and the percentage of β-pinene found among the total terpene concentration. Plotted symbols reflect family codes keyed to table 1.

Although mean heights of families of interior origin differed by about 14 cm (table 2), individual seedlings differed by as much as 60 cm (fig. 1). Unlike the terpene classifications, the mean heights for hybrid families are not predictable from the mean heights of parental lines. Yet, the results are encouraging because large amounts of variation in seedling height and in terpene composition for seedlings of interior origin increase the possibilities of detecting relationships suitable for indirect selection.

Correlation coefficients were calculated for the entire data set and for three subsets involving seedlings of interior, hybrid, and coastal origin. Correlations based on the entire data set show numerous statistically significant relationships between individual terpenes and height (table 3). Yet, as illustrated in figure 1 for β-pinene, most of these relationships reflect intrinsic differences between the varieties. In general, seedlings of hybrid or coastal origin were taller than those from the interior. All terpenes that are characteristically high in the coastal variety had a positive relationship with seedling height; those terpenes that are typically high in the inland variety had a negative relationship with height. Thus, correlations involving data from all seedlings contribute little toward understanding genetic relationships between terpene composition and growth.

Correlations involving seedlings of coastal or interior origin should express the genetic relationships between terpene composition and growth potential more clearly. But the results suggest a lack of genetic correlation (table 3). First, no significant relationships were found for seedlings of the coastal variety. Admittedly, the number of observations was small, and the seedlings were poorly adapted for the inland environment in which they were growing. Secondly, most of the significant relationships indicated for the interior variety (table 3) involve terpenes (α-pinene, citronellol, citronellyl acetate, and geranyl acetate) that do not differ to any large extent between

Table 3.--*Simple correlation coefficients between seedling height and terpene concentration*

Leaf oil	Data set: All data (170 seedlings)	Inland variety (66 seedlings)	Hybrids (75 seedlings)	Coastal variety (29 seedlings)
Santene	[1] -0.52*	-0.08	-0.53*	-0.05
Tricyclene	- .42*	.33*	- .47*	- .10
α-pinene	.55*	.35*	.40*	.37
Camphene	- .43*	.30	- .45*	.01
β-pinene	.56*	.16	.53*	.11
Sabinene	.46*	.21	.44*	.04
Myrcene	.44*	.03	.47*	- .27
3-carene	.16	.30	.17	- .25
α-terpinene	.34*	.19	.38*	.05
Limonene	- .48*	.00	- .45*	- .08
β-phellandrene	.53*	.13	.49*	- .07
Ocimene	- .27*	.11	.10	.29
γ-terpinene	.27*	.13	.33*	.27
Terpinolene	.27*	.19	.36*	- .11
Linalool	.10	.01	.02	.17
Unidentified A	.15	.01	.08	.13
Unidentified B	.11	.30	.12	.28
Borneol	.10	.26	.09	.12
Terpinen-4-ol	.34*	.00	.36*	.06
α-terpinol	.28*	.24	.22	.18
Citronellol	.29*	.34*	.04	- .19
Bornyl acetate	- .47*	- .06	.51*	- .04
Citronellyl acetate	.07	.57*	.15	- .06
Geranyl acetate	.12	- .40*	.32*	- .16

[1] *Statistical significance at the 1% level of probability.

varieties. Finally, a positive relationship in inland seedlings was indicated for tricyclene in a situation where a negative relationship would have indicated a genetic correlation. A negative relationship is expected because tricyclene, a member of the camphene group, is at relatively high concentrations in the inland variety. Consequently, if rapid growth is associated with terpene composition of coastal flavor, a negative relationship would be expressed.

Low values of the correlation coefficients within the two varieties imply that pleiotropism does not govern relationships between terpene composition and growth rate. Since pleiotropism involves the expression of dissimilar traits from the same set of genes, pleiotropic effects would be discernible in nearly perfect relationships.

Correlation coefficients for coastal and inland seedlings suggest that genes controlling terpene composition and growth potential are segregating independently. This conclusion is also supported by the wind-pollinated progenies of tree 7, the interior tree segregating for typically coastal terpenes. Both tall and short seedlings produced relatively high or low percentages of β-pinene (fig. 1, family 0). A similar relationship between height and the concentration of the other typically coastal terpenes was also evident within the wind-pollinated progenies of tree 7. Thus, coastal linkage groups involving rapid growth and high concentrations of β-pinene, the sabinenes, and the terpinenes are not evident in the interior variety.

On the other hand, correlations involving the hybrid data set (table 3) do not support independent segregation. Individual seedlings of hybrid origin had terpene compositions that ranged from interior types to coastal types. And, a positive relationship existed between seedling height and the degree of coastal flavor to the terpenes (table 3). Yet, figure 1 shows that these correlations result from family means rather than from correlations among individuals within families: the tallest hybrid family had terpenes of a distinctly coastal flavor; the shortest families had terpenes of interior flavor.

The relationship between mean height for hybrid families and terpene composition does not appear to be accidental. Tree 7, the interior tree segregating for coastal terpenes, combined with tree 98 to produce hybrids with terpenes that ranged from coastal intermediate to coastal types. Of the 90 hybrid families included in the original tests (Rehfeldt 1977), the seedlings produced from this cross were the tallest. Moreover, tree 25, identified as segregating for some terpenes of coastal flavor, produced hybrids that were slightly above average in height and intermediate in terpene composition. Trees 16 and 19, segregating for no coastal terpenes, produced hybrids that expressed a resemblance to the interior variety for both growth and terpene composition. Thus, the mean height for a hybrid family was directly related to the percentage of the typically coastal terpenes within the interior parental line. But, the mean height of the actual parental lines was not related to the segregation of genes for typically coastal terpenes (table 1). Are these results feasible biologically?

The data suggest that linkage equilibrium in the interior variety has been approached, but not achieved. In addition to genes controlling terpenes, tree 7 undoubtedly has small linkage groups that contain genes typical of the coastal variety. From analyses of the nursery performance of intervarietal hybrids, Rehfeldt (1977) concluded: "Interracial hybridization combines two differentially coadapted genetic systems. The performance of individual hybrid families depends not only on the degree to which specific parental genotypes integrate but also on the degree to which specific gametes integrate." Thus, the mean growth of a hybrid family is related to the proportion of the germ plasm that is of coastal origin. Because tree 7 had more linkage groups of coastal origin than any of the other inland trees, gametes from tree 7 integrated best with gametes of the coastal variety. The result was balanced, coadapted hybrid genotypes (family 7X98) with a strong resemblance to the coastal variety; on the average, these hybrid families should express relationships between growth rate and degree of coastal flavor to their terpenes. In addition, if linkage groups of coastal origin are approaching equilibrium, a relationship between growth rate and terpene composition would not be expected in wind-pollinated progenies of inland trees, particularly if genes of coastal origin are at low frequencies. Consequently, because of a lack of correlation within families, it seems advisable to assume that linkage equilibrium has been achieved between growth rate and terpene composition of the inland variety.

CONCLUSIONS

Practical implications of these results are limited. Because linkage seems to be near equilibrium, the use of terpenes for indirect selection of fast-growing inland genotypes would be inefficient and impractical. However, tests of intervarietal hybrids (Rehfeldt 1977) suggest a high potential of hybridization for improving the growth rate of the inland variety while maintaining cold hardiness. Chemical analyses of leaf oils may provide a rapid means of selecting genotypes of the inland variety that will combine best with coastal gametes.

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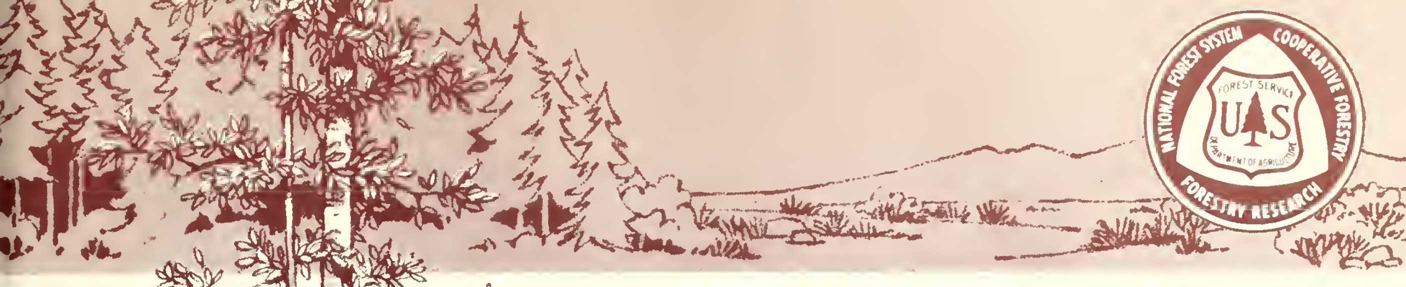

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LINEAR MEASUREMENT: A METHOD OF ESTIMATING FASCICLE NUMBERS FOR LARCH CASEBEARER POPULATION SAMPLING

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ABSTRACT

Branch samples collected from 23 plots in northern Idaho and western Montana in 1975 had a combined mean distribution of 3.13 fascicles/inch (1.23 fascicles/cm) of branch length. By subsampling, it is possible to determine cumulative lineal inches of branch necessary to obtain a sampling unit of 100 fascicles for a plot, eliminating the need for counting fascicles on each sample.

KEYWORDS: *Coleophora laricella*, larch casebearer, population sampling

Customarily, larch casebearer populations have been sampled by taking four 18-inch (45.7 cm) long branches per tree at midcrown and determining the number of larch casebearer per 100 fascicles (spur shoots) (Webb 1953, 1957; Eidmann 1965; Rush 1972; Ciesla and Bousfield 1974). A requirement of this method is counting fascicles to determine a uniform sampling unit of 100 fascicles. In 1975, we began work to develop a means of sampling population intensities of the larch casebearer that would eliminate the need to count fascicles on each branch sample, which would be more efficient and equally accurate.

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METHODS

Branch samples were collected from 23 plots in northern Idaho and western Montana during April and June 1975 (fig. 1). Four branches were collected at midcrown, with pole pruners, from each of 5 to 10 trees on each plot. In the laboratory, 100 fascicles were counted on each branch, starting from the distal end. Lengths of branches were then measured and recorded for each sample of 100 fascicles. Measurements were expressed as mean numbers of fascicles per inch of branch per plot.

Figure 1.--Plot locations for larch casebearer sampling in northern Idaho and western Montana.

RESULTS

Sample plots over a large geographic area provided a range of mean fascicles per inch of growth from a low of 2.45 (0.96/cm) to a high of 3.55 (1.40/cm) (table 1).

Table 1.--*Mean fascicles/inch/plot*

Plot	n	Mean fascicles/inch	Mean fascicles/cm	$\pm S_{\bar{x}}$ [1]
1	28	2.87	1.13	0.0577
2	40	2.97	1.17	.0723
3	39	2.45	0.96	.0616
4	40	3.55	1.40	.0752
5	16	3.36	1.32	.1279
6	40	3.10	1.22	.0860
7	40	3.02	1.19	.1112
8	39	3.11	1.22	.0562
9	40	3.22	1.27	.0730
10	37	3.51	1.38	.1136
11	25	3.10	1.22	.0732
12	38	2.86	1.13	.0612
13	36	2.94	1.16	.0742
14	40	3.38	1.33	.0554
15	31	2.96	1.17	.0591
16	40	3.35	1.32	.1217
17	40	2.96	1.17	.0553
18	40	2.71	1.07	.0576
19	40	3.26	1.28	.0772
20	40	3.38	1.33	.1230
21	60	3.06	1.20	.0529
22	55	3.29	1.30	.0757
23	60	3.32	1.31	.0993
All plots combined	904	3.13	1.23	.0192

[1]Expressed in fascicles/inch.

Pooling data from all plots provided a mean of 3.13 fascicles per inch (1.23 fascicles/cm) of branch growth, with a $S_{\bar{x}} = 0.0192$. At this fascicle density, 32 inches (81.28 cm) of lineal growth would have provided a sample base of 100 fascicles on these plots, as shown in the following tabulation:

Fascicles/inch	*Fascicles/cm*	*Sample length** (Inches)
2.4	0.94	42
2.5	0.98	40
2.6	1.02	39
2.7	1.06	37
2.8	1.10	36
2.9	1.14	34
3.0	1.18	33
3.1	1.22	32
3.2	1.26	31
3.3	1.30	30
3.4	1.34	29
3.5	1.38	29
3.6	1.42	28
3.7	1.46	27

*Sample length rounded off to nearest inch.

Variation in fascicle density between plots may be explained by tree characteristics such as branch growth rate as influenced by stand density, dominance, and previous insect and disease activity.

RECOMMENDATIONS AND CONCLUSIONS

To allow for variation in fascicle density between plots and to maintain a uniform sampling procedure between plots, a 36-cumulative-lineal-inch (91.4-cm) sample of six 6-inch (15.24-cm) samples per branch is recommended. This would assure that enough sample material is collected in the field to minimize the possibility of not achieving a mean 100-fascicle sampling unit for a plot at the time of laboratory examination. The extra sample length should accommodate any variation in fascicle density that may arise between plots. However, if a branch at the time of collection appears atypical, the collector should count 100 fascicles to maintain the 100-fascicle sample base.

The sampling procedure would consist of collecting a branch from a tree (fig. 2), which would then be cut into six 6-inch (15.24-cm) pieces as shown in figure 3. This same procedure would be continued until the entire plot had been sampled. Upon completion of the sample collection, a 10-percent subsample of the samples for a plot would be used to calibrate the remaining samples to a 100-fascicle sampling unit for the plot. On each branch in the subsample, 100 fascicles would be counted and the

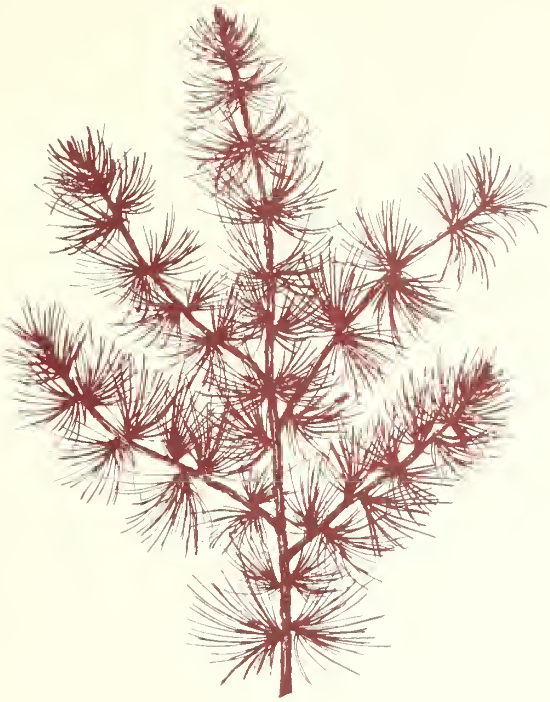

Figure 2.--Larch branch collected from midcrown.

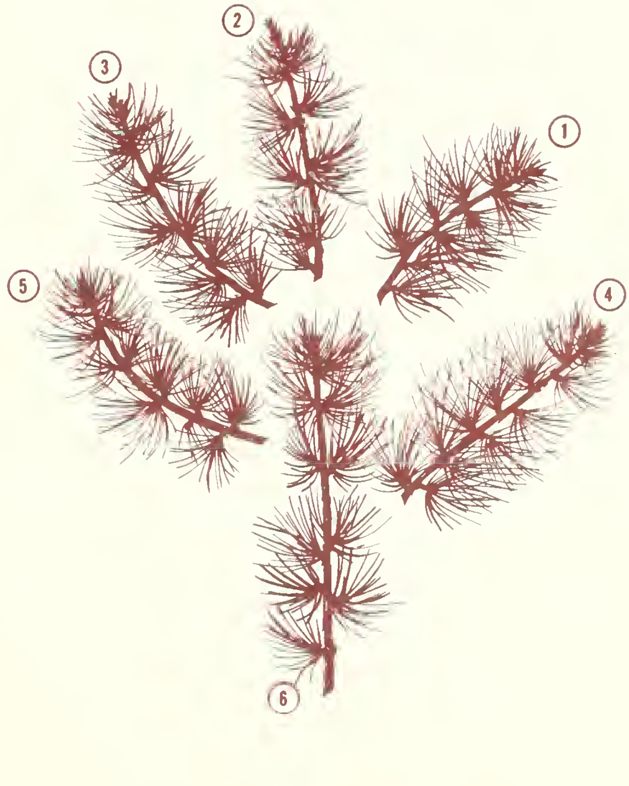

Figure 3.--An illustration of a 36-cumulative-lineal-inch (91.4-cm) sample of six 6-inch (15.24-cm) samples per branch to obtain 100 fascicles.

cumulative branch length recorded. The mean fascicle density for the plot would be calculated and the sample length for the remaining branches determined as shown in the following example.

Plot sample:

10 trees
40 branches, 4/tree at midcrown

Subsample calibration:

Subsample No.	*Fascicles*	*Inches*	*Fascicles/inch*
1	100	33	3.03
2	100	29	3.45
3	100	30	3.33
4	100	31	3.23

With a mean fascicle density of 3.26/inch (1.28/cm) for the plot, the required sample length for the remaining samples would be:

$$\frac{100 \text{ fascicles}}{3.26} = 31 \text{ inches (sample length rounded off to nearest inch).}$$

Verification

This sampling procedure was applied to larch casebearer pupal population sampling on 12 plots in 1977. Four branches were collected at midcrown from 18 trees on plots 1 through 6 and 10 trees on plots 7 through 12. Each plot was individually calibrated using a 10 percent subsample. Plot means for fascicle density were calculated and the sample lengths for the remaining branches were determined (table 2).

Table 2.---*Results of subsample calibrations on 12 plots 1977*

Plot	n	$\bar{x}$ fascicles/inch	$\bar{x}$ fascicles/cm	Sample length applied to remaining samples
				Inches
1	8	3.53	1.39	29
2	8	3.45	1.36	29
3	8	3.33	1.31	30
4	8	3.36	1.32	30
5	8	3.26	1.28	31
6	8	3.35	1.32	30
7	6	3.38	1.33	30
8	6	3.66	1.44	28
9	4	3.70	1.46	27
10	4	3.26	1.28	31
11	6	3.30	1.30	30
12	6	2.96	1.17	34

To determine how well this method of estimating 100 fascicles worked, all branches (excluding those used for calibrating the plots) were reexamined and the actual number of fascicles per branch recorded. A chi-square test was used to test the hypothesis that the estimated sampling unit was within ±10 percent of a mean 100-fascicle sampling unit for each plot at the 10 percent significance level as shown (Freese 1960).

$$\chi^2_{(n)df} = \frac{\sum_{i=1}^{n} (x_i - \mu_i)^2}{\sigma^2}$$

x_i = estimated number of fascicles in the i^{th} plot using the new technique
μ_i = actual number of fascicles in the i^{th} plot using the standard technique
n = number of plots
σ^2 = the required accuracy (for example ±10 percent of the mean at the 10 percent significance level)

The calculated χ^2 value at 12 df was 1.69 corresponding to a table value of 18.5 at the 10 percent significance level. Therefore, the results of this study indicate that the proposed sampling design satisfies the accuracy requirements specified.

Although the variation in number of fascicles between branches may be relatively high within a plot, the mean number of fascicles per branch for a plot is very close to 100 (table 3).

By using a linear measurement sampling method and a 10 percent subsample to calibrate individual plots, it is possible to determine cumulative lineal inches of branch necessary to obtain a uniform 100-fascicle sampling unit for a plot without counting fascicles. Accuracy was maintained and efficiency was improved by using this sampling procedure with the sampling being completed in one-half the time compared to when fascicles were previously counted.

The authors feel this method of sampling will also apply to any life stage of the larch casebearer where population levels are expressed as number of insects per 100 fascicles.

Table 3.--*Mean fascicles per branch by plot*

Plot	n	$\bar{x}$	$S_{\bar{x}}$	Range	
				Minimum	Maximum
1	64	98.5	1.2067	74	117
2	64	101.8	1.4187	77	130
3	64	96.9	1.4505	69	119
4	64	97.5	1.4658	72	127
5	64	103.2	1.5753	74	144
6	64	101.4	1.1041	80	122
7	34	100.9	1.8638	78	117
8	34	97.2	2.0575	72	130
9	36	102.4	1.6844	81	122
10	36	102.4	1.3264	88	125
11	34	99.7	2.2505	63	116
12	34	97.0	1.3008	81	115
All plots combined	592	99.96	0.4511	63	144

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HYDROCHEMICAL INFLUENCES ON THE FISHERY WITHIN THE PHOSPHATE MINING AREA OF EASTERN IDAHO

William S. Platts and Susan B. Martin[1]

ABSTRACT

Hydrochemical analysis of selected streams in the upper Blackfoot River drainage showed waters in these streams were in a near-natural state, with possible modification from surrounding land uses. Stream hydrochemistry and physical condition of fish indicated the fishery was in good condition. No influences from present phosphate mining were found that threatened fish health or survival. Hydrochemically, the Blackfoot system is capable of producing a good cutthroat trout fishery, but high levels of nutrients probably restrict optimum cutthroat trout populations.

KEYWORDS: fish, water quality, heavy metals, surface mining, phosphate.

In 1977, 83 phosphate mining leases covered 43,370 acres (17,551 ha) of Federal lands in southeastern Idaho. The Bureau of Land Management (BLM) and the Forest Service (FS, USDA) 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. Open pit mining operations in the study area have previously caused sediment and petroleum pollutants to enter Angus Creek[2], a

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[2]Platts, William S. 1970. Aquatic habitat studies in the Angus Creek drainage-Stauffer Mine pollution. USDA For. Serv., Intermt. Reg., Caribou National Forest, Pocatello, Idaho. 18 p.

Blackfoot River tributary. Since this polluting period, progress has been made by the mining corporation toward containing mine-caused pollutants. However, the acceleration of surface phosphate mining throughout southeastern Idaho will eventually result in increased sediment in the streams and increased sediment transport throughout most of the upper Blackfoot system (G. Dennis Kelly, Forest Hydrologist, Caribou National Forest, Pocatello, Idaho, personal communication). The increased sedimentation will likely result in detrimental effects on aquatic life in the Blackfoot system.

From 1970 through 1976, general conditions of the aquatic environment and biota of the Blackfoot River drainage, including fish populations, were investigated to give baseline information for future assessment of mining impact in the drainage. The fishery and its relationship to environmental conditions other than hydrochemistry will be discussed in future reports. This hydrochemical study evaluated environmental changes, why they occurred, and the results of these changes. For the purposes of this study, a comparison was made of hydrochemical conditions and heavy metal concentrations in the area as compared to published findings on chronic and acute levels known to affect fish health.

Heavy metal-fish relationships are difficult to determine because elements other than well-known poisons have not been assayed as stressing agents on fish. Usually it is the quantity of the element as it relates (synergistically or antagonistically) to all the other solutes that determines its toxicity. Besides acute and chronic toxic levels, there are also tolerable and favorable levels of dissolved materials. For example, phosphate is an absolute requirement for all life, yet at high levels it can be detrimental to and cause mortality in fish.

STUDY AREA DESCRIPTION

The study area is located in Caribou County, Idaho, within the Soda Springs Ranger District (fig. 1). The study streams are in the Blackfoot River drainage, a major stream in the Caribou National Forest, Diamond Creek Planning Unit. The study streams drain watersheds encompassing past, present, and proposed phosphate mining that have and could in the future detrimentally affect the stream environments (Platts 1975).

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

The study streams are mainly within the mountain valley bottomlands landtype that is nearly level to gently sloping, and tends to flatten out in the immediate stream vicinity. Streambanks have a high vegetative productivity potential and are often flooded during spring and early summer.

The mean annual precipitation varies from 20 to 30 inches (51 to 76 cm), mainly in the form of snow. Mean annual runoff is 10 inches (25 cm). The hydrochemical data indicated that surface waters are very fertile and when good physical habitat is present, high fish standing crops occur.

Fish populations in the drainage may be affected by irrigation diversions, degraded irrigation return flows, and intensive streambank grazing by livestock. In addition, much of the stream environment has been modified by beaver to form ponds.

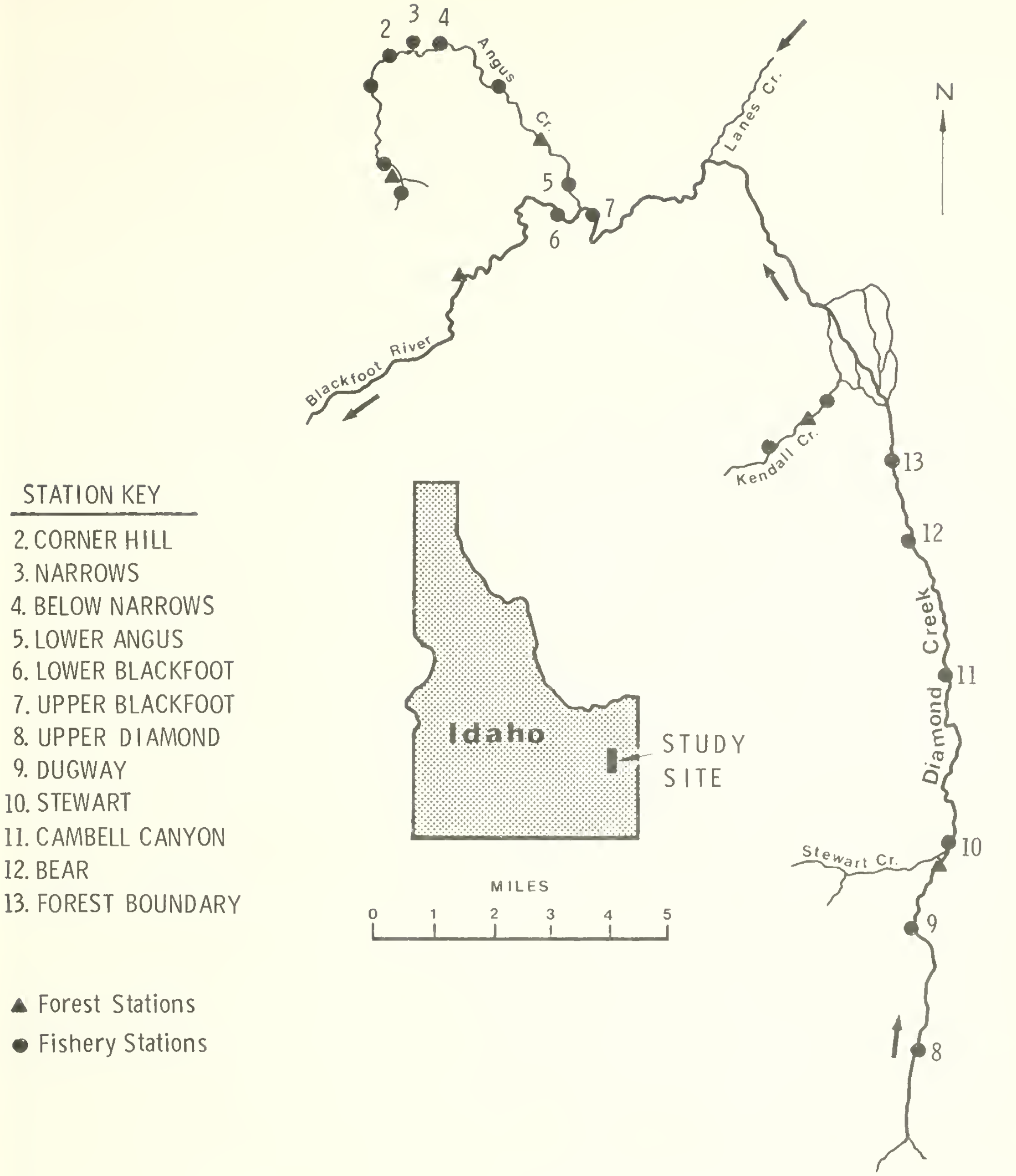

Figure 1.--Study streams and location of water sampling stations.

Study Streams

Angus Creek

Angus Creek contains cutthroat trout (*Salmo clarki* Richardson), one or two species of sucker (*Catostomus catostomus* Forester, *C. platyrhynchus* Cope), dace (*Rhinichthys* spp.), redside shiner (*Richardsonius balteatus* Richardson) and sculpin (*Cottus* spp.). The Angus Creek fish population from the downstream end of the narrows upstream to within 800 yards (730 m) of its headwaters is dominated by cutthroat trout. The upper 800 yards (730 m) of stream is barren of fish (1970-1976) except for a small, newly constructed reservoir where trout survival and growth has been excellent.

In Angus Creek from the narrows downstream to its mouth, the fish population is composed mainly of dace, redside shiner, and sculpin. Angus Creek is believed to be an important spawning and rearing area for cutthroat trout that later move into the Blackfoot system.

Observation and water analysis have demonstrated that the Angus Creek headwaters have received sediment and petroleum products from past mining operations. Streambank cover has been reduced by livestock grazing and beaver.

About 92 percent of Angus Creek is in bottomlands with low gradient channels in an alluvial valley. For part of its length, Angus Creek flows through a steep, V-shaped canyon.

Peak runoff usually occurs between mid-April to late May as a result of snowmelt, but the base flow is mainly from springs. Streamflow changes radically in the headwater area because of water diverted for mining. Angus Creek drains 13.9 mi^2 (36 km^2) and has a mean annual maximum discharge of 176 ft^3/s (299 cm/m). The channel averages about 6,500 feet (1,980 m) in elevation above mean sea level and varies from 6,397 to 7,100 feet. The streamside vegetation is composed of grass, willow, and sagebrush. Other streams in the study area are similar to Angus Creek.

Blackfoot River

The Blackfoot River produces trophy-size cutthroat trout. Trophy-size cutthroat trout also migrate from the Blackfoot Reservoir up the river to spawn in tributary streams. The Blackfoot River above the reservoir contains cutthroat trout, rainbow trout (*Salmo gairdneri*), sucker, dace, redside shiner, sculpin, brook trout, (*Salvelinus fontinalis*), and possibly brown trout (*Salmo trutta*).

Diamond Creek

Diamond Creek joins Lane's Creek to form the Blackfoot River. At present there is little mining development in the Diamond Creek area except for exploration on the Stewart Creek drainage. Several mines are proposed to go into production in this drainage in the future.

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. The stream is inhabited by beaver which dam the stream and cut stream side vegetation; riparian vegetation is grazed by cattle that also trample the banks.

Irrigation diversion and stream splitting near its mouth, often cause portions of Diamond Creek to dry up during summer and fall.

Kendall Creek

Kendall Creek once drained into Diamond Creek, but has been diverted into Spring Creek. Kendall Creek is 3 mi (4.8 km) long and has an average channel gradient of 6 percent, which results in poor fish habitat in this reach. Below the Forest boundary, Kendall Creek flows onto the Diamond Creek valley and stream gradient becomes much lower.

The stream provides a minor spawning environment for cutthroat trout. Mining and livestock grazing have occurred within the Kendall Creek watershed, but upstream from the National Forest boundary these uses have little impact.

FUTURE SITUATION

Accelerated phosphate mining throughout southeastern Idaho will most certainly increase sediment delivery to streams (USDA Forest Service 1976). The stream channel lengths receiving pollutants from mined areas will increase from 17.4 mi (28.0 km) in 1976 to 39.7 mi (63.9 km) by 1999.

Ore location and mining methods will disrupt headwater streams. As an example, the proposed watershed area to be disturbed by mining in the Angus Creek drainage is comprised of 315 acres (127.5 ha). This area consists of 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 of this magnitude will have adverse influences on Angus Creek.

The combination of landforms, soil, vegetation, and water runoff often results in unstable stream conditions even when in the undisturbed state. Fish, through their evolutionary adaptation, maintain their health and population stability under most natural conditions. When land uses such as phosphate mining cause stress above natural levels, population instability and decline usually follow.

At present, the full impact of surface mining on the biota is difficult to detect, quantify, understand, or solve because of financial and methodological limitations.

Surface mining in the study area will probably have great impact on aquatic habitat. As mentioned, some streams have already been influenced by surface mining, but there are little data to evaluate the environmental consequences. The present report, in conjunction with following papers on fish population dynamics, macroinvertebrate-fish population relationships and aquatic structure conditions, will provide these data and furnish a basis for evaluating future changes in the drainage.

METHODS

Hydrochemistry

Two types of sampling stations were used to determine stream hydrochemistry. One type, designed for the fishery studies, was randomly selected, located on aerial photographs, and marked with numbered metal stakes for identification. The other type was selected to fit the needs of a water quality and quantity monitoring program of the Caribou National Forest. These stations were generally located where the stream crossed the Forest Service boundary. Samples from the different stations yielded similar results, but the combination of the data allowed a more accurate description of the study area.

Selected Forest Stations

Water sampling was done under the guidance of Dennis Kelly, Caribou National Forest Hydrologist, commencing in August 1974 and continuing monthly. Samples were collected at midstream, using a DH48 (Developed by Federal Interagency Sedimentation Project) depth-integrated sediment sampler. The sample was transferred to a plastic bottle, iced, and delivered to the Ford Chemical Laboratory, Salt Lake City, Utah, within 7 days after collection. Samples were analyzed within 7 days after arrival at the laboratory. Tests for water temperature, pH, and stream discharge were done in the field, and those for other parameters were performed in the laboratory.

Random Fishery Stations

Sampling commenced at these stations in the summer of 1970 and continued on a semiregular basis through 1976. Samples were generally taken during high flow in May, during the cutthroat spawning period in May and June, and during low summer flows in August. Some minor sampling was done on an intermittent basis over the remainder of the year. Water samples were collected at each station from riffle areas at middepth. Samples were collected in inert plastic bottles that had been stripped with acid and cleansed with hot distilled water. A 4-oz (114-ml) water sample was collected for heavy metal analysis, and a 16-oz (454-ml) water sample was collected for the remaining tests. For the heavy metal analysis the smaller bottle was acidified with 1 ml of HNO_3.

Samples were frozen and remained frozen until delivery to the laboratory. Samples were analyzed using standard methods at the Idaho Department of Health and Welfare Laboratory in Boise, Idaho.

Fish Tissue Analysis

Four cutthroat trout were collected at each random fishery station. The fish were placed in plastic bags, frozen, and later analyzed for tissue heavy metal concentration at the Idaho Department of Health and Welfare Laboratories in Boise, Idaho.

RESULTS AND DISCUSSION

Hydrochemistry

Results of analyses made on water samples collected from the streams during 1970-1976 are given in tables 1 through 4. These seasonal and mean values include samples collected by the Caribou National Forest, as well as those collected for the fisheries study.

Angus Creek

The 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, when considered singly describe a good environment for a salmonid population (table 1). Levels of conductivity, total dissolved solids, suspended sediment and turbidity were within limits recommended by McKee and Wolf (1971) to support a good mixed fish fauna.

Analysis for phosphorus compounds demonstrated the high level of this element in the drainage. Mean values for dissolved (ortho) phosphate (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 higher level that should be allowed in streams flowing into lakes (Federal Water Pollution Control Administration 1968).

Total phosphorus in rivers of the United States usually ranges from 0.01 to 0.1 mg/liter. The Angus Creek value for orthophosphate is higher than this, but this may be a natural condition due to the geological nature of the drainage.

The moderate concentrations of nitrogen compounds (NO_3-N averaged 0.21 mg/liter) present 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 during spring runoff of Angus Creek (11 Nephleometric Turbidity Units (NTU)) is slightly higher than the recommended 10 NTU (FWPCA 1968). This may be due to the high amount of particulate matter in Angus Creek, which in turn is reflected in its high fertility. The majority of materials being removed from the watershed were in the form of dissolved solids (mean value 210 mg/liter).

The samples show an apparent seasonal trend, with values for parameters such as hardness, total alkalinity, and total dissolved solids increasing as waterflows decreased in the fall and winter. At the same time, values for suspended sediment,

Table 1.--*Seasonal and mean values for hydrochemical conditions in Angus Creek, a tributary in the Blackfoot River system, 1970-1976. Sample size in parentheses*

Season	Hardness	Dissolved oxygen	Total alkalinity	pH	Total solids	Total dissolved solids
	mg/l $CaCO_3$	*mg/l*	*mg/l $CaCO_3$*		*mg/l*	*mg/l*
Spring[1]	117		130	6.5-8.7	179	180
Summer	123		145	7.0-10.8	244	200
Fall	151		157	6.9-10.0	276	221
Winter	175		167	[2]N.T.	257	215
Mean	142(249)	[3]12(9)	150(233)	(51)	243(87)	210(236)

	Suspended sediment	Turbidity	Temperature	Conductivity	COD	Carbon total org.
	mg/l	*NTU*	*°C*	*mS/cm*	*mg/l*	*mg/l*
Spring	28	11.0	4	319	N.T.	N.T.
Summer	13	2.6	12	280	7.1	2.3
Fall	7	3.1	8	319	7.1	2.1
Winter	13	3.0	0.5	309	N.T.	N.T.
Mean	18(180)	7.6(254)	7(189)	318(180)	7.1(37)	2.1(17)

	P total	PO_4 Ortho (diss.)	NH_3-N	Total Kjeldahl-N	NO_3-N	NO_2-N
	mg/l	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
Spring	0.19	0.37	N.T.	1.7	0.23	0.02
Summer	.25	.14	0.02	1.9	.18	.02
Fall	.14	.05	.03	1.7	.25	.00
Winter	.12	.12	N.T.	2.1	.16	.09
Mean	.22(253)	.11(68)	.02(17)	1.8(180)	.21(190)	.04(104)

[1]Spring: April, May
Summer: June, July, August
Fall: September, October
Winter: November-March

[2]N.T.:not tested

[3]Data available for D.O. are listed as a mean only; seasonal breakdown of values is not available.

turbidity, and nutrients generally decreased in conjunction with waterflow. Other parameters tested showed little or no change in value over time. These same trends are also generally the case for the remaining streams in the study area.

Blackfoot River

Hydrochemical values for the Blackfoot River were similar to Angus Creek (table 2), suggesting the river water provides a good environment for salmonids but possibly is too fertile for optimum conditions. The turbidity, chemical oxygen demand (COD), total organic carbon, and nitrate were significantly lower in the Blackfoot River than in Angus Creek. This may reflect a dilution factor in the larger stream, as well as less development in the Blackfoot River watershed above Angus Creek. Total orthophosphates in the Blackfoot River are higher than the recommended limits (FWPCA 1968; McKee and Wolf 1971).

Table 2.--*Seasonal and mean values for hydrochemical conditions from selected sites on the Blackfoot River, 1970-1976. Sample size in parentheses*

Season	Hardness	Dissolved oxygen	Total alkalinity	pH	Total solids	Total dissolved solids
	mg/l $CaCO_3$	*mg/l*	*mg/l $CaCO_3$*		*mg/l*	*mg/l*
Spring	142		145	6.5-8.8	197	198
Summer	155		149	5.6-7.2	280	239
Fall	154		183	4.8-8.4	288	208
Winter	201		188	6.5-7.7	246	230
Mean	144(117)	14(4)	155(113)	(30)	248(22)	211(57)

	Suspended sediment	Turbidity	Temperature	Conductivity	COD	Carbon total org.
	mg/l	*NTU*	*°C*	*mS/cm*	*mg/l*	*mg/l*
Spring	49	4.2	4	355	N.T.	N.T.
Summer	17	2.1	10	366	5.5	1.7
Fall	7	1.0	7	334	10.0	1.3
Winter	6	1.1	1.5	378	N.T.	N.T.
Mean	24(95)	2.2(125)	6(96)	352(95)	6.5(16)	1.5(8)

	P total	PO_4 Ortho (diss.)	NH_3-N	Total Kjeldahl-N	NO_3-N	NO_2-N
	mg/l	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
Spring	0.21	0.09	N.T.	1.8	0.17	0.0
Summer	.18	.12	0.01	1.6	.13	.0
Fall	.18	.08	.02	1.9	.10	.0
Winter	.14	.11	N.T.	1.8	.10	.0
Mean	.20(117)	.09(36)	.02(8)	1.7(95)	.1(89)	.0(88)

Diamond Creek

Chemical analyses of Diamond Creek water samples were, in most cases, comparable to those for Angus Creek and Blackfoot River (table 3). Values for mean annual hardness, suspended sediment, COD, and Kjeldahl N were higher than in the Angus Creek and Blackfoot River samples, while total dissolved solids and conductivity decreased. All values when considered singly 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 is a highly productive stream.

Kendall Creek

Chemical values for Kendall Creek were, in virtually all instances, less than for the streams previously discussed (table 4). A decrease in the average dissolved phosphate concentration (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 smaller fish density compared to other streams in the study area.

Table 3.--*Seasonal and mean values for hydrochemical conditions in Diamond Creek, a tributary in the Blackfoot River System, 1970-1976. Sample size in parentheses*

Season	Hardness	Dissolved oxygen	Total alkalinity	pH	Total solids	Total dissolved solids
	mg/l $CaCO_3$	*mg/l*	*mg/l $CaCO_3$*		*mg/l*	*mg/l*
Spring	129	N.T.	116	6.6-7.7	N.T.	188
Summer	180	N.T.	155	7.5-8.0	N.T.	192
Fall	177	N.T.	171	N.T.	N.T.	199
Winter	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.
Mean	157(52)		148(52)	(30)		193(52)

	Suspended sediment	Turbidity	Temperature	Conductivity	COD	Carbon total org.
	mg/l	*NTU*	*°C*	*mS/cm*	*mg/l*	*mg/l*
Spring	95	11	3	295	N.T.	N.T.
Summer	36	4	9	293	3.3	N.T.
Fall	7	0.6	5	301	15.0	N.T.
Winter	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.
Mean	48(52)	5(52)	6(96)	296(95)	8.0(24)	

	P total	PO_4 Ortho (diss.)	NH_3-N	Total Kjeldahl-N	NO_3-N	NO_2-N
	mg/l	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
Spring	0.22	0.13	N.T.	4.3	0.24	0.0
Summer	.17	.10	N.T.	1.7	.13	.0
Fall	.14	N.T.	N.T.	1.7	.11	.0
Winter	N.T.	N.T.	N.T.	0	N.T.	.0
Mean	.17(49)	.11(11)		2.02(5)	.15(49)	.0(49)

Metals

Dissolved heavy metals, commonly found in waters polluted by industrial mining operations, have been confirmed as being toxic to the aquatic biota (Cairns and Scheier 1957; Lloyd 1960, 1961; Lloyd and Herbert 1962; Mount and Stephan 1967; Tarzwell and Henderson 1960). However, difficulty exists in determining the actual metal concentration that is toxic to fish.

Toxicity depends on the fish species (Lloyd 1960), water temperature (Chapman 1973), pH, dissolved oxygen concentration, total hardness, and other chemical parameters. In addition, metals and other elements may interact antagonistically to negate the toxicity of a metal in solution. In general, fish mortality results from exposure to excessive concentrations of a metal, while continuous low levels of a metal produce chronic effects such as behavioral changes, reproductive failure or fry mortality (Chapman 1973). Both ultimately affect the survival of a species in a stream.

Table 4.--*Seasonal and mean values for hydrochemical conditions in Kendall Creek, a tributary in the Blackfoot River System, 1970-1976. Sample size in parentheses*

Season	Hardness	Dissolved oxygen	Total alkalinity	pH	Total solids	Total dissolved solids
	mg/l $CaCO_3$	*mg/l*	*mg/l $CaCO_3$*		*mg/l*	*mg/l*
Spring	165		144	6.9-8.8	N.T.	204
Summer	115		112	7.9	N.T.	203
Fall	126		139	7.1-7.8	N.T.	201
Winter	163		159	7.3	N.T.	199
Mean	128(31)	13(4)	124(31)	(19)		201(26)

Season	Suspended sediment	Turbidity	Temperature	Conductivity	COD	Carbon total org.
	mg/l	*NTU*	*°C*	*mS/cm*	*mg/l*	*mg/l*
Spring	12	1.0	2	276	N.T.	N.T.
Summer	23	.8	6	312	2.3	0.8
Fall	11	11.0	5	300	5.3	.9
Winter	7	.5	4	163	N.T.	N.T.
Mean	13(52)	3.3(34)	3(25)	295(52)	3.7(6)	.9(6)

Season	P total	PO_4 Ortho (diss.)	NH_3-N	Total Kjeldahl-N	NO_3-N	NO_2-N
	mg/l	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*
Spring	0.12	0.05	N.T.	1.8	0.14	0.01
Summer	.08	.04	N.T.	1.5	.16	.01
Fall	.05	.03	N.T.	1.7	.23	.0
Winter	.06	N.T.	N.T.	2.0	.16	.01
Mean	.08(30)	.04(23)		1.8(6)	.18(27)	.01(27)

Heavy metal concentrations in the streams studied were generally quite low (table 5). Levels of iron in Angus Creek, Blackfoot River, and Kendall Creek (130-140 µg/liter) are approaching the toxic concentration of 200-1,000 µg/liter (McKee and Wolf 1971). When related to the buffering action of high hardness and alkalinity in the streams, these concentrations should have no detrimental effect on salmonids.

Chronic mercury toxicity usually occurs from 3-12 µg Hg/liter, while acute toxicity results from concentrations of 4-20 µg Hg/liter (McKee and Wolf 1971). Higher levels of mercury become tolerable as hardness increases. Mercury levels in Angus Creek, Diamond Creek, and the Blackfoot River are within an acceptable range, since in the hard waters of the study area readings up to 5.0 µg/liter probably have no effect on fish. However, mercury in the environment at these readings may be approaching levels that can be toxic to salmonids.

Any disturbance in the watershed may tend to alter the concentrations of any or all of these metals. In aquatic systems lead, zinc, copper, and cadmium are highly synergistic and can result in a combined toxicity greater than their individual concentrations (Chapman 1973). Since these metals are all present at detectable levels in the Blackfoot drainage, any increases in their concentrations might result in toxicity to fish.

Table 5.--*Concentrations of heavy metals in water samples collected from selected streams in the Blackfoot River drainage from 1970-1976 in μg/liter*

	As	Cd	Cr	Cu	F	Fe	Pb	Hg	Se	V	Zn
Angus Creek											
Mean	20	3.4	5.0	5.0	1.0	130	10	3.0	2.0	$\leq$40	17
Min-max	0-10	0-280	0-10	2-16	0.09-0.17	10-65	10-10	2-3	0-10	0-70	2.8-25
85% C.I.[1]	0-50	0-5	1-10	1.2-12	0.6-3.0	90-270	10-10	2-3	0-5	3-41	10-25
Sample size	10	35	10	20	20	80	8	24	10	30	10
Blackfoot River											
Mean	2.0	4.0	4.0	4.0	1.0	130	10	$\leq$2.0	2.0	$\leq$50	10
Min-max	0-10	0-140	0-10	0-10	0.09-0.1	20-41	10-10	0.3-8	0-10	0-100	2-20
85% C.I.	0-5	0-5	1-6	2-8	0.6-3	120-300	10-10	5-6	0-5	0-60	6-16
Sample size	5	13	5	9	8	30	8	10	5	13	5
Diamond Creek											
Mean	2.0	5.3	3.0	3.0	0.1	[2]N.T.	N.T.	$\leq$5.0	4.0	$\leq$55	15
Min-max	0-10	0-240	0-10	2-4	0.08-0.12	N.T.	N.T.	5-9	0-10	0.0-100	2-30
85% C.I.	0-5	0-5	0.07-6	3-4	0.6-3	N.T.	N.T.	5.0-5.2	0.8-7	2-180	9-22
Sample size	5	26	5	5	23	N.T.	N.T.	21	5	26	5
Kendall Creek											
Mean	0.0	0.0	2.0	3.0	N.T.	140	N.T.	N.T.	0.0	0.0	10
Min-max	--	--	--	--	N.T.	140-140	N.T.	N.T.	--	--	--
85% C.I.	--	--	--	--	N.T.	140-140	N.T.	N.T.	--	--	--
Sample size	1	1	1	1	N.T.	6	N.T.	N.T.	1	1	1

[1]C.I. = confidence interval

[2]N.T. = not tested

Note: Heavy metal concentrations did not vary by season.

Fish Tissue Analyses

Table 6 lists results of chemical analyses for heavy metal concentrations in various fish tissues from the study area. In fish, the liver, kidney, and gills tend to concentrate and hold larger amounts of heavy metals than do most of the other organs.

In studies on the Clark Fork River of Montana, Van Meter (1974) found a mean concentration of cadmium in trout liver of 0.69 ppm by weight (μg/g). This concentration was generally above the 0.2-0.74 μg/g range found in fish from the Blackfoot River drainage (mean value for all samples was 0.44 μg Cd/g body weight).

The relatively high mean level of Zn found in the gills, 30.72 μg/g, indicates the tendency toward metabolic concentration of this element. Lloyd (1960) found Zn concentrates in the gills of fish, so high levels in this tissue were expected.

The results of the mercury analyses show a tendency toward concentration of the element in heart tissue. This trend appears to correlate with the slightly higher mercury levels found in the water (table 5), and differs from other studies that correlate tissue concentration with fish age (Potter and others 1975), length and weight (Scott 1974), condition (Hannerz 1968), or sediment concentration of the metal (Schroeder 1974).

Van Meter (1974) made similar findings in his Clark Fork studies, where mercury increases in the water were generally accompanied by increased concentrations in fish muscle. The higher vanadium concentrations in the liver may also be a result of this tendency. However, more detailed studies must be made before any definitive cause and effect statements can be made about the Blackfoot drainage.

Table 6.--*Heavy metal concentration (μg/g of body weight) in cutthroat trout tissues from the Blackfoot River drainage, 1976*

Collection location	Heart Hg[1]	Liver Cd	Liver V	Gills Cu	Gills Zn
Angus Creek Below Narrows	5.36	0.567	<4.7	0.445	26.5
Angus Creek Lower	<0.37	0.275	<4.6	<0.53	33.6
Angus Creek Two Pines	2.13	<0.2	<4.6	<2.3	23.5
Angus Creek Corner Hill	<0.76	0.474	<4.7	<1.38	28.5
Blackfoot River Lower	3.42	0.18	<3.9	2.66	22.2
Blackfoot River Upper	<0.67	<0.2	<4.7	3.76	45.1
Diamond Creek Upper	9.61	0.74	<4.9	<0.53	29.9
Diamond Creek Forest Boundary	4.52	0.49	<4.9	2.58	37.9
Diamond Creek Dugway	7.07	0.508	<5.0	<1.69	26.7
Diamond Creek Cambell Canyon	<0.33	0.56	<4.7	<0.66	24.2
Diamond Creek Bear Canyon	1.12	0.497	<4.5	0.669	33.8
Drainage average	2.82	0.44	4.55	1.52	30.72

[1]Recovery of a known concentration of mercury from tissue was 184 percent. Evidently a positive interference in the method resulted in the abnormal recovery. Therefore, realistic values for the samples might be 50 percent of the reported value.

Some authors have analyzed heavy metal concentrations in composite fish muscle samples (Lucas and others 1970; Uthe and Bligh 1971; Kelso and Frank 1974). This tends to make their average values lower than those found in analysis of specific tissues. Whole fish tissue analysis for copper (Kelso and Frank 1974), showed mean concentrations of 1.13 μg Cu/g dry weight. When comparing this value with the 1.52 μg/g average found in the Blackfoot drainage, it should be noted that this latter value is from gill tissue analysis, where the metal is probably more concentrated. Thus, the actual value for whole fish from the Blackfoot drainage based on the literature is probably lower than that of Kelso and Frank, and well within acceptable limits (0.7 μg 1.56 μg Cd/g whole body tissue, Kelso and Frank 1974).

SUMMARY

Hydrochemical analysis indicated that waters in the study area are in a near natural state, with possible modifications from surrounding land uses. No single parameter proved to be a major limiting factor in degrading fish health, lowering fish density, or adversely affecting fish community structure. Fish tissue analysis showed that no single metal was affecting fish health. Present mining activity does not appear to degrade water quality at this time. As hydrochemical conditions in this study are related to aquatic structure and streamside environments in companion studies, limiting factors may show up.

The Blackfoot River and tributaries are presently supporting a cutthroat trout fishery. However, we believe that the Blackfoot River, Angus Creek, and Diamond Creek are too fertile for a highly producing cutthroat trout fishery. Thus, any future land use that adds to this fertility could significantly depress the cutthroat trout fishery.

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PLANT NUTRIENTS IN FLYASH FROM BARK-FIRED BOILERS

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ABSTRACT

Flyash from bark-fired boiler plants was found to be a low strength fertilizer, having a beneficial combination of essential micro- and macronutrients. Analysis shows the nutrient level to be low but also of long duration, which enhances the use of flyash as a source of plant nutrients.

KEYWORDS: soil nutrients, wood residue utilization, flyash utilization.

Gradual prohibition of open refuse burning and increasing prices and intermittent supplies of fossil fuels, particularly natural gas, have prompted many forest products plants to use bark as fuel. Burning logging residues or grasslands to release nutrients to the soil has been practiced for a long time. Flyash from forest products boiler plants produces similar residues! Why not use flyash for a soil amendment? Are these residues suitable as a nutrient supply? Might there be some additional favorable qualities as a soil amendment? What limitations are there on the application of this material?

Flyash is produced when burning gases contact the relatively cool surface of the firebox or burning chamber wall. The gas then changes to a solid ash which is then removed in precipitators or scrubbers. Dirty bark causes the formation of volcanic glass which can help to improve tilth of heavy soils. A rule of thumb is--bark from 1 million board feet of logs will provide 1 ton of flyash. This rule suggests that in western Montana more than 1,000 tons of flyash are disposed of per year. At this time an indeterminate amount of bark is still burned in tepee burners. It is logical to assume that eventually much of this bark will be utilized for firing boilers. Consequently, the supply of flyash will increase proportionately.

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[1]Respectively: Research Forester, located at Intermountain Station's Forestry Sciences Laboratory, Missoula, Montana; and Soil Scientist, Soil Conservation Service, Deer Lodge, Montana.

The following analysis was obtained for a boiler plant fired with bark residues. About 17.5 tons of wet hog fuel produces 121,000 pounds of steam per hour for 24 hours which also produces 622 pounds of ovendry flyash. Because this boiler plant is fired with a traveling grate feed system, the flyash contains some unburned carbon. This amounted to 3.02 percent by weight of the material obtained from the stack precipitator. One boiler plant operating 350 days per year will generate 86 to 90 tons of flyash per year. Another plant, with a much larger boiler installation, generates more than 260 tons of flyash per year.

This Research Note reports on preliminary analysis of flyash from bark-fired boilers. The work is part of a research effort directed toward increasing utilization and product alternatives from forest and processing plant residues.

FLYASH RESEARCH

Literature pertaining to flyash from boiler plants is quite abundant. However, most of it deals with coal-fired powerplants. Plass and Capp (1974) determined that alkaline flyash, rich in some plant nutrients, can be used to help reclaim acidic mine spoils. Before treatment the spoils were extremely acidic, and after treatment pH and soil phosphorus increased significantly. Infiltration rates were improved, soil porosity was increased and percolation was increased to a depth of 4 feet (Plass and Capp 1974).

SAMPLING, ANALYSIS, AND RESULTS

Three flyash samples were taken from each of four boiler plants in the Missoula, Montana, area. Ash samples were taken from different sources at each plant such as (1) below the cyclone that captures the ash, (2) at the conveyor before it is dumped for pickup, and (3) at the dump site. These boilers are fired with sawmill and plywood residues. This residue is mainly bark because sawdust and planer shavings are used in pulp or particleboard.

Flyash material was prepared by sieving through a 1-mm sieve to make all samples of uniform texture and get rid of unburned material. Two 5-gram samples were randomly picked from each collection for analysis. They were then placed in funnels lined with filter paper and leached. One of the paired 5-gram samples was leached four times with 100 ml of water at 31°C, and the other leached four times with ammonium acetate at 30°C, and one normal concentration. Each leaching was analyzed individually.

An atomic absorption unit was used to analyze leachate samples for calcium, copper, magnesium, manganese, potassium, sodium, and zinc. The water-leached samples were additionally analyzed for nitrate with a nitrogen meter, phosphate with a calorimeter, and pH with an electronic pH meter.

WATER LEACHATE

Table 1 shows the average of water soluble materials in the four leachings. Lower concentrations were noted with each successive leachate. (Tables 4 and 5 in the appendix show the results of each successive leaching.) The figures in table 1 are the means for four water-leached samples from each source. The extremely high sodium content in the source A sample was later traced to contamination from boiler blowdown effluent. The $\bar{x}$ source is the mean of samples A-D for all the various elements tested.

Recalling that 1,000 parts per million is the same as 0.1 percent, these figures indicate low concentrations of all elements compared to regular commercial fertilizers. Elements destructive to plants are low in concentration; potassium, a beneficial element, is comparatively high in concentration.

Table 1.--Mean flyash nutrient concentration--water leaching[1/]

Source	Ca	Cu	Fe	K	Mg	Mn	Na	Zn	pH	NO3	PO4
	Parts per million									P/m	Mg/ℓ
A	1,250	2.3	7.0	1,280	235	4.6	[2/] 1,755	0.10	9.5	4.3	6.6
B	1,250	1.4	1.0	1,848	5,100	2.5	74	0.04	8.5	8.7	2.0
C	2,200	0.9	0.6	1,056	4,065	0.7	26	0.01	8.6	6.5	0.6
D	107,200	3.1	2.9	6,168	268	2.5	58	0.57	12.2	82.3	0.4
Grand Mean	27,975	1.9	2.9	2,588	2,417	2.6	[3/] 535	0.18	9.7	25.5	2.4

1/ Table 1A in the appendix gives the results of each leaching.
2/ Extremely high sodium content. Subsequent investigation determined this source to be contaminated from water clarification process effluent.
3/ Excludes contaminated source A.

ACETATE LEACHATE

Table 2 shows the average element availability when leached four times with ammonium acetate. The purpose of this procedure is to provide a basis for determining the availability of nutrient elements through successive moist periods. That is, ammonium acetate was used to test the residual elements that would be available over a longer period of time than suggested by water leaching. Ammonium acetate was chosen for its known ability to flood the exchange and replace the nutrients available in the exchange. In this way the residual elements can be analyzed. The relatively high concentration of calcium agrees with previous findings (Metz and Wells 1965).

Statistical Analysis

In many cases, one or more sources for a fixed element have variances differing from the rest (tables 4 and 5 in the appendix). This causes the F-test of analysis of variance to give significant results too often. Therefore, the t-statistic (or an approximation when variances were significantly different) was used to detect differences between sources for selected elements. All tests were performed at the 5 percent level.

Table 2.--Mean flyash nutrient concentrations by ammonium acetate leaching[1/]

Source	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
	Parts per million							
A	5,313	2.3	3.3	1,138	245	26	1,109	7.8
B	14,069	2.0	3.9	1,682	697	199	52	19.3
C	14,669	2.5	3.2	3,418	1,015	186	2,994	23.0
D	3,860	3.0	3.0	2,362	528	38	233	4.1
Grand Mean	9,478	2.5	3.4	2,150	621	112	1,097	13.6

1/ Table 2A in the appendix gives the results of each leaching.

Table 3.--T-test results for selected elements

Type of leaching	Elt.	Sources A vs. B	A vs. C	A vs. D	B vs. C	B vs. D	C vs. D
Water	Ca	0	-2.36	-8.62*	-3.45*	-8.63*	-8.55*
	K	- .51	.27	-1.15	.71	-1.00	-1.20
	NO_3	- .73	- .55	-6.19*	.31	-5.34*	-5.79*
	PO_4	2.23	3.08	3.12	2.33	2.37	.44
Acetate	Ca	- .96	-4.44*	1.01	- .07	1.12	5.08*
	K	- .33	- .69	- .53	- .49	- .26	.27

* Indicates significant difference between sources at the 0.05 probability level.

The results of these t-tests appear in table 3. For the water leachings, source A is not significantly different from either source B or C in mean flyash nutrient concentrations of Ca, K, NO_3, and PO_4. And, except for a difference in Ca concentration, source B is no different from source C. Sources A, B, and C each differ from source D in mean concentrations of Ca and NO_3.

In acetate leachings, the average concentration of Ca for source C significantly differs from both sources A and D. Other sources exhibit no statistical differences for Ca and K.

For the water leaching, 55 percent of the time there is a decrease in the parts per million from leaching 1 through leaching 4. In acetate leaching, the decrease in each leaching occurs 48 percent of the time.

DISCUSSION AND CONCLUSIONS

The current practice of using flyash as a landfill is becoming increasingly costly. Available landfill areas are becoming more distant from the boiler plants. A solution to the problem is utilization rather than disposal.

Wood is a very low component of processing plant residues. However, the inner bark contains nutrients. Hence, flyash from bark can be expected to be a better fertilizer source than wood ash.

Chemical analyses suggest that flyash could serve as a fertilizer or soil amendment. Flyash can be added to pulverized bark for physically improving heavy clay soils.

Present farming practices tend to overfertilize, which reduces water quality and wastes nutrients. Generally, fertilizer application has to be increased each year to get the same result as the previous year because organic material is lacking as a water-nutrient reservoir. Flyash appears to be superior because of its natural timed release of nutrients over an extended period of time. Preliminary field testing shows growth response still evident 3 years after application. A low-grade fertilizer meets plant needs over time better than a high-concentrate fertilizer.

Flyash is high in potassium, which enhances its value as a fertilizer since plants absorb more potassium than any other element. Furthermore, the ash has a fairly good balance of nutrients, that is, the macronutrients and micronutrients are favorably proportioned in large and small quantities.

A low-grade fertilizer can be effective if plant nutrients are available in quantities needed by plants and not in such excess amounts as to pollute the soil or damage the plant. Also, where soil fertility is not fully depleted, a low-grade fertilizer can be a better supplement than a potent fertilizer that will overfertilize.

Fertilizer prices will follow rising petrochemical prices. One response of fertilizer users will be to seek alternative sources for fertilizer. Flyash can provide a new source, and perhaps, provide additional revenues to wood products industries. Although further work must be done on application rates and specific uses, the prospect of using flyash as a fertilizer warrants serious consideration.

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Table 4.--Water leaching--sample data

Source	Leaching		Ca	Cu	Fe	K	Mg	Mn	Na	Zn	pH	NO3	PO4
			Parts per million									P/m	Mg/ℓ
A	1		1,800	6.0	10.4	3,060	200	7.0	3,460	.22	10.0	8.4	11.8
	2		200	1.4	5.8	760	40	3.6	1,700	.10	9.7	4.0	7.4
	3		1,400	1.2	6.2	721	300	4.0	1,100	.06	9.2	2.8	4.5
	4		1,600	.6	5.6	580	400	3.6	760	.02	9.1	1.9	2.8
		$\bar{x}$	1,250	2.3	7.0	1,280	235	4.6	1,755	.10	9.5	4.3	6.6
		s	718.8	2.5	2.3	1,189.0	153.5	1.6	1,201.3	.09	.42	2.9	3.9
B	1		1,000	2.0	2.0	4,600	3,000	4.0	186.4	.16	8.3	25.9	3.6
	2		800	1.8	1.0	1,620	4,400	2.0	74.0	0	8.7	4.8	2.4
	3		1,600	1.0	.9	750	6,400	2.0	24.2	0	8.7	2.3	1.1
	4		1,600	.6	0	420	6,600	2.0	12.0	0	8.4	1.6	1.0
		$\bar{x}$	1,250	1.4	.98	1,848	5,100	2.5	74	.04	8.5	8.7	2.0
		s	412.3	.66	.82	1,903.5	1,716.6	1.0	79.3	.08	.21	11.6	1.2
C	1		1,800	2.0	1.6	2,800	3,300	2.0	68.0	.04	8.8	17.9	1.0
	2		2,400	1.2	.4	820	4,400	.2	21.2	0	8.6	4.0	.5
	3		2,600	.2	.2	382	4,600	.2	8.0	0	8.2	2.3	.4
	4		2,000	.2	0	221	3,960	.4	5.0	0	8.6	1.9	.3
		$\bar{x}$	2,200	.9	.55	1,056	4,065	.70	26	.01	8.6	6.5	.55
		s	365.1	.87	.72	1,109.1	575.8	.87	29.2	.02	.25	7.6	.31
D	1		128,400	4.2	3.4	18,500	363	2.2	176.0	.40	12.3	115.5	1.3
	2		118,600	3.8	3.8	4,600	291	3.6	40.0	.86	12.3	79.5	.2
	3		109,600	2.2	2.4	950	274	2.2	8.4	.60	12.2	79.5	.1
	4		72,200	2.0	2.0	620	144	2.0	6.2	.42	12.1	54.7	.04
		$\bar{x}$	107,200	3.1	2.9	6,168	268	2.5	58	.57	12.2	82.3	.40
		s	24,563.9	1.1	.84	8,417.1	91.2	.74	80.5	.21	.10	25.0	.61

Table 5.--Acetate leaching--sample data

Source	Leaching	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
A	1	7,650	2.7	6.0	3,225	291	27	2,905	11.3
	2	6,250	2.5	3.0	794	284	30	935	9.2
	3	4,050	2.1	2.0	316	207	24	351	4.8
	4	3,300	1.9	2.0	216	196	21	245	5.7
	$\bar{x}$	5,313	2.3	3.3	1,138	245	26	1,109	7.8
	s	1,998.9	.37	1.9	1,414.2	49.9	3.9	1,235.2	3.0
B	1	40,000	4.6	5.8	6,087	938	365	158	49.0
	2	12,700	1.1	2.5	394	933	224	28	12.0
	3	2,750	1.2	3.5	145	515	122	13	9.0
	4	825	1.0	3.7	100	400	86	10	7.0
	$\bar{x}$	14,069	2.0	3.9	1,682	697	199	52	19.3
	s	18,053.8	1.8	1.4	2,939.8	279.9	125	70.9	19.9
C	1	18,250	3.3	3.8	13,125	1,013	104	11,200	17.6
	2	16,500	2.2	2.6	296	1,450	245	388	26.0
	3	14,250	2.4	3.2	146	905	222	222	26.0
	4	9,675	1.9	3.0	105	690	172	165	22.4
	$\bar{x}$	14,669	2.5	3.2	3,418	1,015	186	2,994	23.0
	s	3,709.9	.60	.50	6,471.9	319.9	62.4	5,471.7	4.0
D	1	1,265	5.2	6.0	8,950	798	47	846	6.6
	2	6,075	2.7	2.0	285	447	40	43	4.0
	3	4,850	2.2	2.0	127	188	33	23	3.2
	4	3,250	1.7	2.0	87	677	32	20	2.7
	$\bar{x}$	3,860	3.0	3.0	2,362	528	38	233	4.1
	s	2,081.1	1.6	2.0	4,392.7	269.1	7.0	408.8	1.7

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EFFECT OF COLD STORAGE ON DEVELOPMENT OF SUCKERS ON ASPEN ROOT CUTTINGS

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ABSTRACT

The effect of cold storage on suckering ability of excised roots was determined for 10 aspen clones. Root cuttings were collected in June, August, and October and stored for from 7 to 42 days at 2°C. In addition, cuttings from dormant trees were stored for 175 days to determine if they had cold requirements for suckering. Among clones, there were large differences in capacity to produce root suckers. Cold storage had a small but significant effect on the formation and growth of suckers on root cuttings collected in June and August. As a rule, clones responded similarly to cold storage. Sucker production by root segments from dormant trees was relatively high and was not increased significantly by storage. Incidence of callus formation at the ends of root segments tended to increase with time in cold storage.

KEYWORDS: *Populus tremuloides*, quaking aspen, aspen root cuttings, sucker development, adventitious shoots, chilling requirements.

Aspen (*Populus tremuloides* Michaux) is vegetatively propagated by rooting cuttings taken from adventitious shoots (suckers) arising on excised roots. Roots are often stored at low temperature before culturing root suckers (Benson and Schwalbach 1970; Sandberg 1951; Starr 1971). However, no information is available as to the effect of cold storage on sucker production.

The shoots of physiologically dormant trees generally require a cold period before they resume growth. Under field conditions this requirement is satisfied by natural chilling during the winter months. Roots collected from dormant trees many also have cold requirements that have to be satisfied before they will sucker.

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This study was to determine the effect of cold storage on sucker production from root cuttings taken from 10 aspen clones. Roots were collected in spring, summer, and fall and stored for various periods in a cold room. Suckering from stored roots was compared with suckering from roots planted immediately after they were collected.

METHODS

Root segments were collected from 10 clones in Logan Canyon, east of Logan, Utah, on June 1 (2 weeks after bud break), August 9, and October 12 (after leaf fall), 1976. After the roots were collected they were rinsed, cut into 8 by 1 to 2 cm segments, and soaked for 30 minutes in an aqueous slurry of 0.1 percent benomyl, a systemic fungicide. Segments from each clone were randomly divided into five groups of eight segments each. One group (control) was planted immediately, and the other four groups were wrapped in moist paper toweling, placed in plastic bags, and stored in the dark at 2°C for 7, 14, 28, and 42 days before planting. Segments were planted horizontally 1.5 cm deep in moistened vermiculite in plastic trays (19.5 by 27.5 cm) with adequate drainage. Each group (eight segments from each clone) was subdivided into four lots of two segments. These were distributed among four plant trays so that each tray contained two segments from each clone. The trays were placed in a growth chamber maintained at a 25°/15°C, 12/12 hour temperature regimen and a 12/12 hour photoperiod and were lightly watered each day. When new trays were added to the growth chamber, they were randomly placed among those already present. Six weeks after the root segments were planted, they were lifted and the number of suckers recorded. The height of the tallest sucker per segment was also noted, along with the occurrence of callus at the ends of the segments.

The storage periods used may not have been long enough to satisfy chilling requirements of root cuttings from dormant trees. Dormant stems generally require more than 2 months of continuous chilling before normal bud break will occur (Barry 1972; Farmer 1968). To make sure that chilling requirements were met, segments from the October collection were also stored for 175 days (October 12 to April 15) and then planted.

RESULTS

The effect of storing aspen roots at low temperatures on subsequent sucker production is shown in table 1. Storage time had a significant effect on suckering from roots collected in June and August, but not on suckering from those collected in October. Storing June roots for 1 week caused a significant increase (30 percent) in sucker production. Thereafter, increased storage time resulted in only minor changes. Sucker production from August roots significantly decreased (34 percent) during the first 2 weeks of storage and then showed little change with an increase in storage time. Differences among clones were highly significant for all three collection dates. Comparisons among clones are shown in table 2. A nonsignificant clone-storage interaction indicated that the clones responded similarly to treatments. When the analysis was limited to sucker production by the controls, there were significant differences between dates. However, when data from all treatments were included in a single analysis, differences between dates were not significant. Thus, cold storage generally had an equalizing effect on the number of suckers produced at different seasons, that is, it reduced the seasonal variation in sucker production. Nevertheless, a significant clone-date interaction indicated that some clones showed considerable seasonal variation in sucker production.

The effect of cold storage of aspen roots on subsequent height growth of root suckers is shown in table 3. Storage only had a significant effect on sucker growth on roots collected in June and August. Sucker heights on June roots were slightly increased by 2 weeks of storage. Longer periods of storage caused approximately 17 percent reduction in growth. On August roots, there were no consistent trends. Sucker heights decreased by 15 percent after 1 week of root storage, increased after 2 weeks,

Table 1.--*Effect of time in cold storage on mean number of suckers produced from aspen root cuttings (8 by 1 to 2 cm)*

Days	Clone 1	2	3	4	5	6	7	8	9	10	Mean
						June Collection					
0	7.4	18.8	9.1	4.2	2.5	9.5	4.5	2.8	4.1	3.1	[1]6.60 b
7	7.4	24.9	11.0	4.5	2.8	10.4	6.6	4.9	5.8	7.4	8.55 a
14	9.4	20.0	10.6	7.1	2.0	9.1	7.8	3.0	2.9	6.9	7.87 ab
28	6.9	24.6	9.5	4.8	2.8	8.2	7.0	5.5	8.9	5.9	8.40 a
42	4.0	22.4	10.5	3.1	1.1	11.9	4.6	3.8	4.0	8.5	7.39 ab
Mean	7.05	22.20	10.20	4.80	2.30	9.85	6.00	3.90	5.10	6.45	7.78
						August Collection					
0	16.1	27.9	13.2	5.9	2.1	14.1	8.1	1.8	4.2	9.1	10.26 a
7	14.6	21.9	10.2	3.8	2.6	13.8	6.5	1.8	6.6	6.6	8.84 ab
14	8.6	20.2	10.1	3.9	1.5	10.9	4.6	1.4	3.0	3.9	6.81 b
28	14.9	16.0	13.0	3.4	1.6	11.1	3.5	2.6	5.0	7.1	7.82 b
42	13.2	18.0	9.6	3.9	3.6	7.4	5.2	2.0	6.5	4.1	7.36 b
Mean	13.50	20.75	11.20	4.10	2.35	11.35	5.45	1.85	5.15	6.20	8.19
						October Collection					
0	20.4	16.6	17.2	2.9	2.2	7.8	7.9	2.1	7.4	3.5	8.80 a
7	14.0	22.0	21.6	4.4	2.2	11.2	7.0	2.1	7.1	0.8	9.25 a
14	18.8	20.4	15.4	2.5	3.0	9.1	5.6	4.0	6.8	2.9	8.84 a
28	13.8	18.4	20.2	3.4	3.9	7.1	5.0	5.0	4.1	3.0	8.39 a
42	14.0	18.0	22.6	8.2	4.2	8.8	4.5	4.0	7.8	2.0	9.41 a
Mean	16.15	19.05	19.50	4.30	3.20	8.85	5.95	3.55	6.65	2.60	8.98

[1] Treatments with no common letter are significantly different at the 5 percent level.

Table 2.--*Comparisons among aspen clones in mean number of suckers per cutting. Clone numbers are in parentheses. Clones are ranked in order of decreasing sucker production. Underlined means were not significantly different (5 percent level) from each other.*

JUNE

(2)	(3)	(6)	(1)	(10)	(7)	(9)	(4)	(8)	(5)
22.2	10.2	9.8	7.1	6.4	6.0	5.1	4.8	3.9	2.3

AUGUST

(2)	(1)	(6)	(3)	(10)	(7)	(9)	(4)	(5)	(8)
20.8	13.5	11.4	11.2	6.2	5.4	5.2	4.1	2.4	1.8

OCTOBER

(3)	(2)	(1)	(6)	(9)	(7)	(4)	(8)	(5)	(10)
19.5	19.1	16.2	8.8	6.6	6.0	4.3	3.6	3.2	2.6

Table 3.--*Effect of time in cold storage on mean height of tallest sucker per aspen root cutting (8 by 1 to 2 cm).*

Days	Clone 1	2	3	4	5	6	7	8	9	10	Mean
					JUNE COLLECTION						
0	15.6	21.0	20.8	47.1	33.7	27.0	21.2	31.9	28.0	27.6	[1]27.29 a
7	19.6	17.1	20.2	39.1	25.4	31.0	25.8	37.4	27.2	27.0	26.97 a
14	17.6	17.8	18.2	34.5	34.7	24.2	28.2	49.2	37.7	29.6	29.03 a
28	18.9	16.0	18.8	31.4	28.5	27.9	22.1	28.9	23.6	27.2	24.41 b
42	18.8	13.9	13.8	30.1	32.4	22.8	22.2	31.7	28.5	26.2	23.89 b
Mean	17.80	17.20	18.35	36.65	30.70	26.70	23.85	35.35	29.40	27.95	24.08
					AUGUST COLLECTION						
0	23.8	21.2	27.7	39.0	44.0	32.5	26.1	34.8	28.5	24.4	29.83 a
7	20.4	20.4	19.6	31.4	38.5	23.9	20.6	40.4	24.3	22.0	25.32 b
14	24.2	17.9	29.7	31.3	35.8	26.2	31.8	40.3	26.7	25.8	28.49 a
28	21.6	19.4	21.9	33.1	45.4	32.0	30.8	46.4	29.3	27.6	29.72 a
42	24.5	16.5	20.7	23.1	31.9	29.9	27.6	30.6	32.1	25.3	26.11 a
Mean	22.75	19.05	25.15	31.10	39.95	28.95	27.40	39.15	28.25	25.00	26.25
					OCTOBER COLLECTION						
0	24.2	18.6	30.1	35.4	45.0	29.9	25.1	37.8	29.2	28.1	30.23 a
7	24.4	23.2	25.1	27.3	44.4	35.2	28.0	41.2	32.0	36.7	31.18 a
14	26.9	24.3	28.2	37.0	43.9	36.6	28.9	44.1	35.7	34.3	34.29 a
28	25.6	19.0	24.9	33.3	44.1	40.4	26.4	45.3	30.2	24.6	31.54 a
42	29.7	23.2	27.9	29.0	42.9	36.1	31.0	36.9	32.4	27.8	32.09 a
Mean	26.25	20.95	27.20	32.75	44.40	35.60	27.95	40.40	31.60	30.05	31.70

[1] Treatments with no common letter are significantly different at the 5 percent level.

and fell again after 6 weeks. Height differences among clones were significant for all three collection dates. Comparisons among clones are shown in table 4. The only roots to show significant clonal differences in response to cold storage were those collected in June. There were significant differences between dates when the analysis was limited to controls. Differences increased when all treatments were included in the analysis. A comparison between mean heights showed an increase with each succeeding collection date from spring to fall. However, a significant clone-date interaction indicated that not all clones follow this general trend.

The effect of cold storage on callus formation at the ends of root segments is shown in table 5. Storage time significantly affected callus growth at the ends of root segments collected in June and October. Numbers of root ends with callus increased with increasing length of storage time to a peak of 28 days and then decreased. A significant clone-storage interaction was only evident for June roots. Differences among clones were highly significant for each of the three collection dates. Comparisons among clones are shown in table 6. There was little difference between June and August roots in the occurrence of callus. However, on October roots, callus was seven times more frequent than on roots collected earlier.

Table 4.--*Comparisons among aspen clones in mean height of tallest sucker per cutting. Clone numbers are in parentheses. Clones are ranked in order of decreasing sucker heights. Underlined means were not significantly different (5 percent level) from each other.*

JUNE

(4)	(8)	(5)	(9)	(10)	(6)	(7)	(3)	(1)	(2)
36.6	35.4	30.7	29.4	28.0	26.7	23.8	18.4	17.8	17.2

AUGUST

(5)	(8)	(4)	(6)	(9)	(7)	(3)	(10)	(1)	(2)
40.0	39.2	31.1	29.0	28.2	27.4	25.2	25.0	22.8	19.0

OCTOBER

(5)	(8)	(6)	(4)	(9)	(10)	(7)	(3)	(1)	(2)
44.4	40.4	35.6	32.8	31.6	30.0	28.0	27.2	26.2	21.0

Table 5.--*Effect of time in cold storage on the number of severed ends of aspen root cuttings (8 by 1 to 2 cm) showing callus formation (maximum of 16 ends per treatment per clone)*

Days	Clone 1	2	3	4	5	6	7	8	9	10	Total
JUNE COLLECTION											
0	0	0	0	0	0	1	0	0	0	0	[1] 1 c
7	0	0	0	1	3	1	0	0	0	0	5 bc
14	0	0	1	2	3	3	0	1	0	0	10 ab
28	0	0	1	5	0	7	0	2	2	0	17 a
42	0	0	1	4	1	2	0	0	0	0	8 abc
Total	0	0	3	12	7	14	0	3	2	0	41
AUGUST COLLECTION											
0	1	0	1	4	1	3	0	0	0	0	10 a
7	0	1	0	1	2	6	0	0	0	0	10 a
14	1	0	0	1	2	2	0	0	0	0	6 a
28	1	0	0	3	1	3	0	0	0	0	8 a
42	0	0	0	1	0	1	0	0	0	0	2 a
Total	3	1	1	10	6	15	0	0	0	0	36
OCTOBER COLLECTION											
0	0	2	7	7	3	13	1	0	0	0	33 bc
7	0	2	3	5	1	14	0	0	0	0	25 c
14	1	2	5	10	10	14	1	3	0	0	46 b
28	5	3	9	7	10	13	3	6	0	0	56 a
42	3	3	4	10	9	15	0	2	0	0	46 b
Total	9	12	28	39	33	69	5	11	0	0	206

[1] Treatments with no common letter are significantly different at the 5 percent level.

Table 6.--*Comparisons among aspen clones in mean percentage of cutting ends that showed callus formation. Clone numbers are in parentheses. Clones are ranked in order of decreasing callus formation. Underlined percentages are not significantly different from each other.*

JUNE									
(6)	(4)	(5)	(3)	(8)	(9)	(1)	(2)	(7)	(10)
17.5	15.0	8.8	3.8	3.8	0.1	0	0	0	0
AUGUST									
(6)	(4)	(5)	(1)	(2)	(3)	(7)	(8)	(9)	(10)
18.8	12.5	7.5	3.8	1.2	1.2	0	0	0	0
OCTOBER									
(6)	(4)	(5)	(3)	(8)	(2)	(1)	(7)	(9)	(10)
40.8	25.4	19.2	13.3	5.8	5.4	5.0	2.1	0.8	0

The effect of 175 days of cold storage on subsequent sucker production by root segments collected in October is shown in table 7. Cuttings from only seven clones were used in this experiment. Sucker production from stored roots was not significantly different from those planted immediately after they were collected.

Table 7.--*Effect of 175 days' cold storage on mean number of suckers per aspen root cutting (8 by 1 to 2 cm) for cuttings collected on October 12, 1976, when trees were dormant.*

Days	Clone 2	4	6	7	8	9	10	Mean
0	16.6	2.9	7.8	7.9	2.1	7.4	3.5	6.88
175	16.8	5.5	8.5	7.1	5.7	10.4	1.6	7.94

DISCUSSION

This study showed that the relative suckering capacity of different aspen clones determined from stored root cuttings is similar to that determined from fresh cuttings. Although cold storage significantly altered the number of suckers produced on cuttings collected on two dates, clones responded similarly to the treatments and therefore the relative differences between clones were not appreciably changed.

Clonal ranking in sucker production showed considerable stability from one date to another (table 2), because most clones showed little seasonal variation in sucker production. However, sucker numbers on the roots of a few clones showed changes of as much as 50 percent from one date to another. Large seasonal variations in sucker production have been reported (Schier 1973b; Tew 1970). Therefore, timing could be critical when evaluating the relative suckering capacities of clones.

During cold storage, sucker production from root segments increased in June and decreased in August; so the seasonal differences between collection dates became insignificant. Inactivation of endogenous growth regulators (inhibitors in June, promoters in August) may be responsible for these changes. The absence of any difference in sucker production between stored and fresh roots in October could mean that hormone concentration in freshly collected roots were at low levels. Schier (1973b) failed to detect auxin, an inhibitor of suckering, in aspen roots collected in October.

Sucker heights showed greater clonal and temporal variation in response to cold storage than sucker numbers. This may have been because numbers of suckers were to a great extent predetermined by the numbers of preexisting shoot primordia (Schier 1973a), whereas sucker growth was affected by the current physiological conditions of the root. The increase in mean sucker height from June to October is probably caused by the accumulation of carbohydrate reserves in roots that occurs during this period (Schier and Zasada 1973). In spite of clone-storage and clone-date interactions, the rankings of the clones were fairly stable among the three collections.

Callus formation was another index of the effect of cold storage on the physiological conditions of root segments. The frequency of the occurrence of callus at the ends of root segments was more closely related to sucker height than to sucker numbers. The most prolific growth of callus occurred on root segments collected in October when maximum sucker height was also recorded. Clones in which callus formation was common were clones that produced large suckers. The relatively close relationship between sucker height growth and callus development probably was the result of both being dependent on the level of carbohydrate reserves. Significant increase of callus with time in storage suggests that hydrolysis of polysaccharides occurred during cold storage, with corresponding increases in readily available sugars (Robinson and Schwabe 1977; Rutherford and Sewell 1972).

There was no evidence that adventitious shoot development was inhibited in excised roots of dormant trees. Root cuttings collected in October had a relatively high suckering capacity compared to cuttings collected in June and August and cold storage did not result in a significant increase in sucker production. Schier (in press), however, found that intact roots of dormant trees had cold requirements. When young dormant trees were girdled or decapitated, they produced few suckers. Suckering was prolific in the spring after cold requirements were satisfied by low winter temperatures.

For the person interested in vegetatively propagating aspen, the results of this study indicate that root cuttings from most clones can be safely held for prolonged periods in cold storage. Being able to store roots gives a great deal of flexibility to the propagation of rooted sucker cuttings. For example, roots from a large number of clones can be collected at different times, stored, and later planted at the same time. Also, roots can be collected in the fall before snow falls, and stored until February or March when the roots are planted. An early start in propagation makes it possible to grow large aspen plants in a single growing season.

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GENETIC VARIATION IN SUSCEPTIBILITY OF WESTERN WHITE PINE TO NEEDLE BLIGHT

R. J. Hoff and G. I. McDonald[1]

ABSTRACT

Ten clones of western white pine differed in their susceptibility to white pine needle blight. Two clones were significantly less infected than the average and two clones were significantly more infected than the average. This variability suggests a simple inheritance, maybe just one or two genes.

KEYWORDS: western white pine, white pine needle blight, genetic variability, disease resistance

Needle blight, a periodically occurring disease of western white pine associated with wet summers, generally affects needles and buds of the lower crown. Under severe conditions, however, most of the crown becomes diseased and death often occurs. Shaw and Leaphart (1960) isolated several organisms from needle-blighted trees. But they considered a *Lecanosticta* species to be the causal organism because it was consistently associated with the disease.

The last severe outbreak was in the late fifties-early sixties. Recent wet springs and summers have led to severe infection in a clonal seed orchard of western white pine resistant to blister rust (*Cronartium ribicola*). Though not welcome, the severe infection presented an opportunity of documenting genetic variation in susceptibility to needle blight.

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[1]Principal plant geneticist and principal plant pathologist, respectively, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

MATERIALS AND METHODS

The seed orchard was established in 1960 at Sandpoint, Idaho (Bingham and others 1963). Clones were selected for their high levels of rust resistance on the basis of progeny test results. Since rust resistance was the only characteristic selected, variation in all other characters can be considered to be random. The seed orchard was designed to provide an experimental area for testing various seed orchard procedures, to determine the long term effects of grafting, and to provide materials for which genetic variation could be documented, as well as for production of resistant seed.

The seed orchard consists of 13 clones arranged in a randomized block design within 14 blocks. Some blocks and clones were incomplete; thus, only a portion of the seed orchard, complete blocks (9) and those clones having at least one ramet per block (10), was used in the analysis (table 1).

The tree crowns were placed into one of three categories: (1) no infection; (2) up to 30 percent of the crown infected; (3) 30 to 60 percent of the crown infected. There were no trees in the sample with more than 60 percent of the crown infected. Since symptoms are most noticeable in the fall, the data were taken in November (1975). The data were analyzed by category, i.e., 1, 2, or 3.

Independence of blocks and clones was determined via a 9 by 10 chi-square table (Snedecor 1966). The sum of all ramets/clone/block comprised the observed value. For example, the eight ramets of clone 17, block 1, were rated 1,2,1,2,3,1,2,1 for a sum of 13. The expected value (14.23) was the product of the mean for a block (1.67) and a clone (1.79) divided by the total mean (1.68) multiplied by the number of ramets/clone/block (8). Differences among clones and blocks were determined by comparing the contribution of each to the overall chi-square for blocks and clones.

Table 1.--*Number of ramets per clone and block*

Clone	Block 1	2	3	4	5	6	10	11	13	Total
17	8	9	10	9	8	8	8	9	8	77
19	9	10	10	8	9	9	10	10	9	84
20	9	7	8	8	7	8	7	8	3	65
21	7	4	5	7	4	3	6	2	6	44
22	10	8	8	8	10	10	8	9	10	81
24	7	10	6	9	9	8	7	6	10	72
37	3	8	7	6	9	9	9	9	7	67
45	5	9	7	5	7	7	8	6	7	61
58	1	5	8	6	2	2	9	6	4	43
65	4	1	4	2	2	4	5	3	4	29
Total	63	71	73	68	67	68	77	68	68	623

RESULTS, DISCUSSION, AND CONCLUSIONS

The interaction chi-square of clones and blocks was not significant (table 2). The among-block variation was also nonsignificant but the among-clone chi-square was highly significant. The contribution of each clone to the total clone chi-square is listed in table 3.

The orchard is located on a flat area that was once a pasture. The trees are spaced at 20 by 20 ft and they were only 20 to 30 ft tall in 1975. It is not surprising, therefore, that there was no difference among the blocks.

On the other hand, the highly significant difference among clones, especially when considering the number of ramets per clone, shows that there is a strong genetic influence of the host on the parasite's ability to infect various white pine trees. Although the mechanism(s) of resistance and mode of inheritance are not revealed by our test, two clones had high resistance (19 and 24) and two clones had low resistance (65 and 37) with the remaining close to the mean, which suggests a simple genetic pattern.

Different levels of infection of individuals and stands, by diseases in general, are nearly always considered to be due to environmental causes. Infection levels of white pine needle blight are frequently higher at the edges of stands. Nonetheless, within this environmentally induced variation there is frequently, possibly always, an underlying genetic factor that also affects the observed variation. Successful management practices are developed only by knowing all the causes of variation--do not forget the genetic component.

Table 2.--*Observed and expected values of western white pine infected with needle blight*

	Block										
Clone	1	2	3	4	5	6	10	11	13	$\bar{x}$	Total
17	13/14.23*	16/17.15	17/17.0	15/15.53	14/14.15	15/14.06	17/14.75	16/16.78	15/14.41	1.79	138/129.36
19	9/10.56	11/12.57	12/11.24	8/9.10	10/10.49	10/10.43	14/12.14	12/12.39	13/10.68	1.18	99/141.12
20	14/15.66	14/13.05	12/13.33	13/13.50	13/12.10	15/13.75	13/12.61	17/14.58	3/5.28	1.75	114/109.2
21	9/9.46	7/6.09	9/6.81	12/9.66	4/5.65	3/4.21	9/8.84	2/2.98	8/8.63	1.43	63/73.92
22	19/19.1	15/15.26	12/13.64	11/13.81	16/17.69	17/17.58	15/14.75	19/16.78	21/18.0	1.79	145/136.05
24	10/8.70	14/13.32	6/7.14	13/10.85	11/11.12	8/9.82	7/9.01	7/7.81	14/12.6	1.25	90/120.96
37	8/7.25	23/20.71	16/16.20	18/14.06	21/21.61	21/21.48	18/22.52	22/22.78	16/17.11	2.43	163/112.56
45	11/8.15	15/15.73	11/10.93	7/7.91	12/11.34	9/11.28	12/13.51	9/10.25	14/11.55	1.64	100/102.48
58	2/1.59	9/8.52	12/12.19	9/9.26	4/3.16	2/3.14	17/14.83	8/10.00	6/6.44	1.60	69/72.24
65	10/9.30	3/2.49	10/8.91	4/4.51	6/4.62	12/9.19	11/12.05	7/7.31	5/9.42	2.34	68/48.72
$\bar{x}$	1.67	1.79	1.60	1.62	1.66	1.65	1.73	1.75	1.69	1.68	
Total	105/ 105.84	127/ 119.28	117/ 112.64	110/ 114.24	111/ 112.56	112/ 114.24	133/ 129.36	119/ 114.24	115/ 114.24		1,049

χ^2 Blocks x Clones = 19.97 with 76 d.f.

χ^2 Blocks = 1.21 with 8 d.f.

χ^2 Clones = 53.92** with 9 d.f.

*Expected = $\bar{x}$ clone (1.79) X $\bar{x}$ block (1.67)/$\bar{x}$ total (1.68) X ramet number (8) = 14.23.

**Denotes significant deviation from the mean at 1 percent probability, 9 degrees of freedom.

Table 3.--*Contribution of individual clones to chi-square and the level of needle blight infection of western white pine*

	Clones									
	19	24	17	20	21	22	45	58	65	37
χ^2	12.57	7.92	0.58	0.21	1.61	0.59	0.06	0.15	7.62	22.6
Infection level	Low	Low	- - - - - - - - - Medium - - - - - - - - - -						High	High

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ESTIMATING LIGHT INTENSITY BENEATH CONIFEROUS FOREST CANOPIES: SIMPLE FIELD METHOD

C. A. Wellner[1]

ABSTRACT

Intensity of light under canopies of coniferous forest can be estimated easily without instruments but with accuracy adequate for numerous administrative and research studies.

KEYWORDS: light intensity estimations, coniferous forests, forest canopies, field method

Field workers on administrative and research projects frequently need a simple but reasonably accurate method for estimating intensity of sunlight under forest canopies. Many years ago during an instrumental study of light intensity under coniferous forest canopies in northern Idaho, the author[2] developed a simple ocular method that has proved useful many times. Because this method does not require instruments and is easy to use, other workers may find it handy.

The method is based on the observed fact that crowns of coniferous trees exert little filtering effect on the passage of light; that is, most sun rays either penetrate openings in the canopy unimpeded or else are almost entirely obstructed by foliage.

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

[2]Wellner, Charles A. 1946. Estimating light intensity in residual stands in advance of cutting. USDA For. Serv., North. Rocky Mt. For. and Range Exp. Stn. Res. Note 47, 4 pp.

As a result, the light pattern beneath the canopy is essentially a mosaic of patches of full sunlight and deep shade. Measurements of light intensities beneath the canopy are primarily of very high or very low intensity and the mean light intensity is an average mainly of extreme values.[3] The problem in any field method of measurement or estimation is largely one of classifying the light pattern into two parts, full sunlight and deep shade, and obtaining the proportion of each. It was found that this classification could be done satisfactorily by direct visual observation.

The method consists of two processes: (1) making ocular observations of light intensity at regular intervals throughout the area studied, listing these as "full sun" or "shade" intensities, and determining the proportion of each, and (2) computing average light intensity for the area by substituting these proportions into a simple formula for calculation.

The individual observation is made by glancing upward at the sun. If the observer's view of the sun is entirely unobstructed or less than half obstructed, he tallies the observation as "full sun." If his view is more than half obstructed, he records the observation as "shade." Most observations can be judged definitely in one class or the other. The observer classifies borderline observations at his discretion. The practice of classifying first one as "full sun," the next as "shade," the next as "full sun," etc. is satisfactory.

An alternative method is to hold a small, light-colored card or page of a pocket notebook horizontally in the hand. The light on the card is tallied as "shade" or "full sun."

The method of selecting observation points may be varied according to the area studied. Any method is satisfactory which obtains good distribution of observation points throughout the given area, an adequate number of points, and the choice of these so that they are either random or systematic, i.e., not influenced by personal selection. At least 100 observations should be made on each study area.

As with all direct-reading methods, observations should be made during June or July, as near midday as possible, and on days when the sun is clearly visible. They should not be made before 10:00 a.m. or after 2:00 p.m. Though a cloudless day is not necessary, the sun must be visible to the observer.

When the proportion of "full sun" and "shade" observations is known, the observer can compute the mean light intensity. The computation consists of multiplying the proportion (percentage) of "full sun" measurements by 100 (the intensity of full sunlight) and the percentage of "shade" measurements by the average intensity of shade, summing the two results and dividing by 100.

$$\text{Mean light intensity} = \frac{A(y) + B(x)}{100}$$

Where mean light intensity is in percentage of full sunlight

A = percentage of "full sun" observations
B = percentage of "shade" observations
x = average intensity of shade
y = intensity of full sunlight (100)

[3] In the instrumental study mentioned, 83 percent of a total of 6,621 direct measurements having an average intensity of 48 percent of full sunlight, were in the 0-20 and 81-100 percent of full sunlight classes.

A value of 7 as an average intensity of shade (x) is used in stands where 10 percent or more of the observations are "full sun," and a value of 3 is used where less than 10 percent are "full sun." A value of 100 is always used for full sunlight intensity.

Use of the formula is illustrated by the following example. Suppose 35 percent of the observations are "full sun" and 65 percent are "shade." Then:

$$\text{Mean light intensity} = \frac{35 \times 100 + 65 \times 7}{100} =$$

$$\frac{3500 + 455}{100} = 39.55 \text{ or } 40 \text{ (percent of full sunlight)}$$

Accuracy of this ocular method is indicated by comparison of estimates made by this ocular method with measurements made by a Shirley radiometer[4] on 18 sample plots, each 0.4 acre (0.16 ha) in area, distributed over a wide range of canopy densities. No comparison showed a difference greater than 6 percent of full sunlight; only one comparison showed a difference greater than 5 percent; 15 of the differences were less than 3 percent, and 6 were less than 1 percent.

From these comparisons it is concluded that for most field studies in which discontinuous measurements of light intensity beneath the canopy are adequate, the method described here can produce satisfactorily accurate estimates.

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[4]Shirley, H. L. 1930. A thermoelectric radiometer for ecological use on land and in water. Ecology 11:61-71.

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FERTILIZING AND CLIPPING EFFECTS ON SEED CAPSULE AND FORAGE PRODUCTION OF ORANGE GLOBEMALLOW[1]

Clay Gautier and Richard Everett[2]

ABSTRACT

Seed of orange globemallow (Sphaeralcea munroana), a forb native to western rangelands, is not readily available because of variability in wildland seed crops. Seed of this forage and reclamation species must be raised under cropland conditions if a dependable seed supply is to be developed. Effects of fertilizers and clipping on seed capsule and biomass production were investigated in a lathhouse study. Clipping extended the flowering period and stimulated vegetative growth. Fertilizing plants in early flower stages and after clipping increased both seed capsule and biomass production. Only plants clipped after seed set produced a second crop of seed capsules.

KEYWORDS: seed production, native forb, globemallow, clipping effects

Orange globemallow (*Sphaeralcea munroana*), a perennial forb, is a forage species for wildlife and livestock on many western ranges (USDA Forest Service 1966, 1969) (fig. 1). Globemallow rapidly occupies disturbed areas and should be useful in reclamation work. Its showy scarlet flowers may also make the species useful in horticulture.

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[1]This is also listed as Journal Series No. 416, Nevada Agricultural Experiment Station.

[2]The authors are respectively biological technician and range scientist located at the Renewable Resources Center, University of Nevada, Reno.

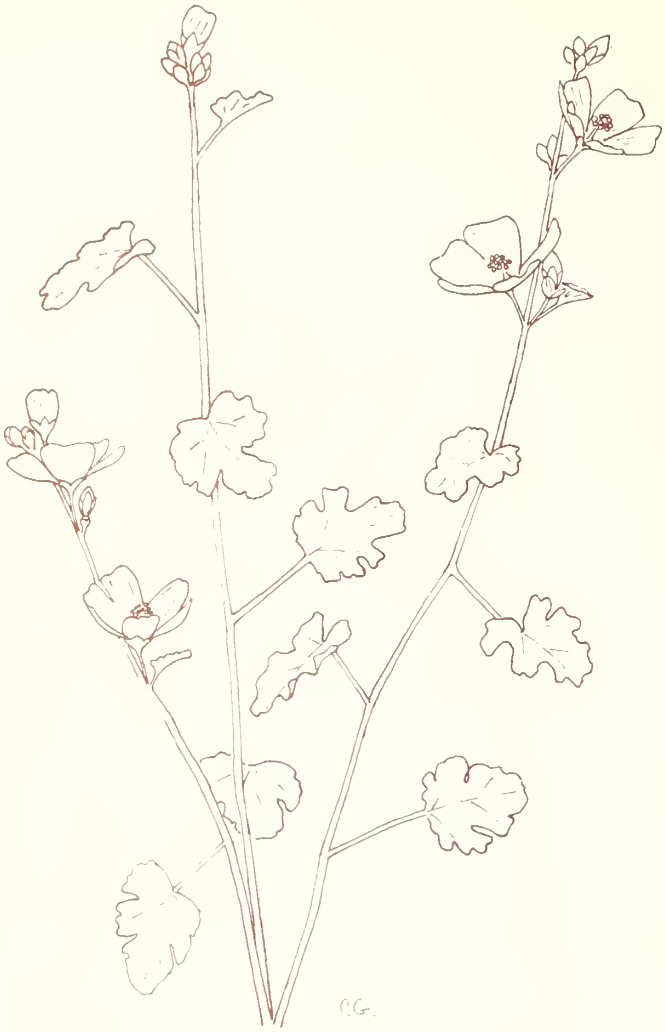

Figure 1.--Orange globemallow in flower (blooms are scarlet).

Seed of globemallow is rarely available. Nearly all seed is presently collected from wildland stands. Variability in wildland seed crops and high costs of seed collection add to the problem. Globemallow seed must be produced under cropland conditions before seed will be reasonably priced.

Cropland seed production of native forbs is still in its infancy and fertilizer requirements for maximum seed production of many wildland species, including globemallow, are unknown. Investigators have found that fertilizers increase the seed production of many plant species. Of the three major nutrients, nitrogen, phosphorus, and potassium (N,P,K), nitrogen has been reported to be the most effective (Williams and Smith 1954; Hawthorn 1952). Phosphorous fertilizer is less consistent than nitrogen in increasing seed production among crops (Schudel 1952) and potassium fertilizer has resulted in few increases in seed production.

Field observations of orange globemallow indicate that flowering and seed capsule production may be correlated to the number of flowering stems produced. Clipping chrysanthemums which have a growth form similar to globemallow, increases branching and flowering (Laurie and others 1968). We wondered if globemallow would respond similarly.

In this study, we attempted to determine the effects of fertilizers (N-P) and clipping on seed capsule and forage (biomass) production of first year globemallow plants.

METHODS

Globemallow plants, raised from seed collected at a single site, were grown for 3 months in a greenhouse until flowerbuds started to form. Plants then were screened for uniform size and vigor and moved to a lathhouse. Plants were grown in deep, paper pot containers (5 by 5 by 30 cm) filled with a loamy sand soil, low in nitrogen and phosphorus.

Three clipping treatments were tested. Plants were either (1) not clipped, (2) clipped in early flowering stages (July 1, 1977), or (3) clipped after seed ripening (August 1, 1977). Dates in parentheses are the dates of the treatments. Leaves and stems were removed to a stubble height of 5 cm when plants were clipped.

Fertilizer treatments tested in conjunction with clipping treatments and the application dates were as follows:

1. Plants fertilized in early flowering stages (June 17, 1977).
2. Plants fertilized immediately after clipping (early flower stage, July 1, 1977; or after seed ripe, August 1, 1977).
3. Plants fertilized in early flowering stages and after either clipping treatment.
4. Plants not fertilized.

Fertilizer was applied at a rate of approximately 100 kg/ha of actual nitrogen in the form of soluble urea ($CO(NH_2)_2$) and 50 kg/ha of actual phosphorus in the form of soluble sodium hypophosphate ($NaH_2PO_4 \cdot H_2O$). Each plant received 2 ml of solution containing 0.056 g urea and 0.063 g sodium hypophosphate each time a fertilizer treatment was applied. All plants received similar amounts of water and light.

The tabulation below shows the combined clipping-fertilizer treatments tested and the number of replicates in each treatment. Replications, each containing 16 plants, were located randomly throughout the lathhouse. Clipping and fertilizer treatments tested were:

Treatments	*Number of Replications*
Not Clipped	
Not fertilized	8
Fertilized in early flowering stages	8
Clipped in early flowering stages	
Not fertilized	8
Fertilized in early flowering stages	8
Fertilized after clipping	8
Fertilized in early flowering stage and after clipping	8
Clipped after seed set	
Fertilized after clipping	4
Fertilized in early flowering stages and after clipping	4

Green weight of foliage and of stems was recorded at clipping time for both clipping treatments. Green weight was also recorded on September 28, when all treatments were "harvested" down to a 2-cm stubble height. We considered green weight to be an adequate measure of relative forage production among treatments because all plants were grown under a constant moisture regimen.

Ripe seed capsules were collected by hand once a week. Actual seed production was not measured because some capsules shed seed before they could be collected.

A one-way analysis of variance test was used to analyze the data. Duncan's multiple range test was used for individual comparisons when F values were significant at the 0.05 level.

RESULTS

Unclipped plants had a flowering sequence similar to plants growing in natural stands. Plants developed flower stalks in late May and completed seed ripening by late July. Growth of unclipped plants ceased when flowering stopped.

Clipped plants had an extended flowering period. Plants clipped in early flowering stages continued flowering through September. Plants clipped after seed set flowered through October and produced a second seed crop. Plants began to flower about 4 weeks after clipping.

Clipping stimulated vegetative growth and, in conjunction with applied fertilizer, substantially increased total plant biomass. Total forage production was greatest in plants fertilized in early flowering stages and after clipping tables. Clipped plants continued to grow until the first hard frosts.

Total seed capsule production was greatest on plants clipped after seed set and fertilized both in early flowering stages and after clipping (table 1). Clipping in early flowering stages reduced the number of seed capsules harvested because flowerbuds removed were not replaced by the plant. Ratliff and Hubard (1975) reported a similar decrease in seed production when California poppy (*Eschscholzie californica*) was clipped in early flowering stages.

Applying N-P fertilizer increased seed capsule production of both unclipped plants and plants clipped after seed set. Fertilizing plants before clipping in the early flowering stages appeared to only increase the number of flowerbuds removed by early clipping and lower the number of seed capsules harvested at a later date.

Plants achieved good initial growth when fertilized. Fertilization after clipping also increased the plant's potential for regrowth. Unfertilized plants produced the least biomass and the fewest seed capsules.

Table 1.--*Seasonal totals for seed capsule and forage production of orange globemallow under various fertilizer and clipping treatments*

Treatment	Seed capsules	Forage (g)
Not clipped		
Not fertilized	[1,2]37.5bc	[3]3c
Fertilized in early flowering stages	53.5ab	8.25bc
Clipped in early flowering stages		
Not fertilized	.75d	4.63c
Fertilized in early flowering stages	2.38d	25a
Fertilized after clipping	15.63cd	16.38b
Fertilized in early flowering stages and after clipping	9.5cd	36.63a
Clipped after seed set		
Fertilized after clipping	24.25bcd	14bc
Fertilized in early flowering stages and after clipping	76.5a	28.75a

[1]Mean number of capsules produced per replicate (16 plants).
[2]Values with dissimilar superscripts are significantly different at the 0.05 level.
[3]Mean forage weight produced per replicate (16 plants).

CONCLUSIONS

Clipping orange globemallow after seed set has potential for increasing seed capsule and forage production. Second seed crops are possible only on clipped plants. If soils are deficient in nitrogen or phosphorus, these elements must be provided if maximum seed capsule and forage production are to occur.

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RESISTANCE OF WESTERN WHITE PINE TO BLISTER RUST: A FOUNDATION FOR INTEGRATED CONTROL[1]

Geral I. McDonald[2]

ABSTRACT

Low-level resistance to blister rust in alliance with other control options such as hazard mapping, Ribes *eradication, rapid early growth of white pine, and branch-canker pruning can greatly expand the outlook for management of white pine in the West.*

KEYWORDS: *Cronartium ribicola; Pinus monticola;* computer simulation; epidemiology

White pine blister rust (*Cronartium ribicola*) has been a major forest disease in North America since its introduction at the turn of the century. We all remember control methods that were tried and discarded. Eventually, management of western white pine (*Pinus monticola*) on National Forest lands was suspended in 1968 (Ketcham and others 1968) until such time as resistant planting stock became available. Some resistant stock is currently available from Regions 1 and 6 of the USDA Forest Service. Outplantings of resistant materials have performed very well (Bingham and others 1973; Steinhoff 1971).

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[1]Originally presented to 68th Western Forestry and Conservation Conference, Seattle, Wash., Nov. 29-Dec. 1, 1977.

[2]Principal plant pathologist, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

High level resistance remains the best single solution, but much could be done to complement resistance and increase management flexibility through the application of our total arsenal of disease management techniques. Particularly promising is the use of low-level resistance, which can be quickly obtained from naturally selected seed (Hoff and others 1976) or extensive breeding programs. Some of the possibilities that can extend the usefulness of low-level resistance are hazard determination, *Ribes* eradication, branch-canker pruning, and accelerated early growth.

First, let us consider *low-level resistance alone*. Several kinds of resistance are known to exist in populations of western white pine (table 1). The effect of immunity imparting mechanisms is obvious, but, what do forms of low-level resistance mean in terms of stand damage? We have constructed a computer simulator (McDonald and others, manuscript in preparation) that allows us to evaluate various alternatives. Output from the simulator is used in the following discussion to demonstrate some possibilities. Input variables have been selected to simulate infection over a 100-year period at Pierce, Idaho.

Table 1.--*Observed resistance mechanisms in* Pinus monticola:Cronartium ribicola *system*

Mechanism of resistance	Resistance type	Hypothesized inheritance	h^2
1. Resistance in secondary needles to a yellow-spot forming race	Vertical	Recessive gene	
2. Resistance in secondary needles to a red-spot forming race	Vertical	Dominant	
3. Resistance in secondary needles to a yellow-green-island spot forming race	Vertical	Dominant gene?	
4. Resistance in secondary needles to a red-green-island spot forming race	Vertical	Dominant gene?	
5. Resistance in secondary needles that prevents spot formation	Vertical	?	
6. Reduced frequency of secondary needle infections	Horizontal	Nondominant gene?	
7. Slow fungus growth in secondary needles	Horizontal	Polygenic?	
8. Premature shedding infected secondary needles	Vertical	Recessive gene	
9. Fungicidal reaction in short shoot	Vertical	Recessive gene	
10. Fungicidal reaction in stem	Vertical	Oligogenic?	0.367
11. Slow fungus growth in stem	Horizontal	Polygenic?	0.21-0.46
12. Tolerance to infection	Horizontal	?	

In the first example we will assume a population of white pine where all the trees have the reduced needle-lesion trait. Mortality is expected to reach about 13 percent in 100 years, not 75 percent as would be the case for trees with no resistance. What would happen if growth rate of the rust in secondary needles could be slowed down so that one more year would be required for the fungus to reach wood, or if needle retention could be reduced to 2 years instead of 3, or if 3-year-old needles could be induced to drop after an unusually heavy infection year (Griffing and Ursic 1977)? The epidemiological result of all these situations is that the mortality curve would reach about 30 percent in 100 years.

We have evidence of a resistance mechanism that slows the growth of the rust on branches and boles. If growth rate were halved, then one could expect about 42 percent mortality in 100 years. Additional kinds of resistance are known and others may be discovered, but for the time being let us take a look at the combined effects of those just discussed. If all the trees contained all three of the mechanisms (reduced needle-lesions, slow fungus growth, and 2-year needle retention), then one could expect about 1 percent mortality from blister rust in 100 years. Although we should work toward this solution, difficulties could be encountered in trying to breed a population where each tree contained all three kinds of resistance. Additionally, we may wish not to put all our eggs in one basket. The rust and climate will surely vary, so we must retain as much genetic flexibility in our pine population as is possible. For this reason and others we should use only as much resistance as is necessary so that the largest gene pool possible can be maintained. In order to maintain a large gene pool, many disease management techniques in addition to resistance must be utilized.

Solution two is *hazard determination*. In my opinion, two *Ribes* species cause the bulk of the damage. These are the so-called upland species, *Ribes sanguinium* and *R. viscosissimum*. I believe this because in most situations basidisopores will not infect pine at a distance greater than about 1,000 ft. In addition, more than 90 percent of the spore load produced by an individual bush will not travel further than about 40 ft (Buchanan and Kimmey 1938). This does not mean that infection never occurs more than 1,000 ft from a bush. It most certainly does (Lloyd 1959; Van Arsdel 1972), but I do not think that such occurrences are in the majority. It is my belief that most trees that become infected will be within 50 ft of a bush. Furthermore, most infections on most trees are nonlethal branch cankers; therefore, damage, measured in terms of mortality rather than percent infected, should be directly related to the relative dispersal patterns of *Ribes* bushes and the white pine trees on most sites. *Ribes* species such as *R. bracteosum* and *R. petiolare* that are known for their ability to produce prodigious spore loads are restricted almost entirely to stream banks. Consequently, damage caused by this source should, in most cases, be local. The upland species, on the other hand, tend to be evenly spaced over the landscape.

The only direct evidence I have concerning this idea is from some experimental field tests that included susceptible materials (table 2). In the cases where upland *Ribes* were present and evenly dispersed, early mortality has been very high. When few upland bushes were present, little infection has resulted to date. These results are based on visual estimates of *Ribes* populations and counts of infected and dead trees. It is essential that dispersal patterns of both trees and bushes be determined on given sites and associated infection levels ascertained. In the absence of such data, we can look at simulation results. The simulator shows an obvious relationship between *R. viscosissimum* density and infection: Less than 1 percent dead after 100 years at one bush/ha; about 2 percent dead at 10 bushes/ha; about 80 percent dead after 100 years at 100 bushes/ha; and 100 percent dead after 45 years at 1,000 bushes/ha.

The reason for abandoning *Ribes* eradication was excessive long distance spread, but may I remind you that western white pine is still doing very well in northern Idaho. At this time it is difficult to say how much of the relatively low level of infection is due to natural selection of resistance and how much to lack of long distance spread.

Table 2.--*Determinations of blister rust hazard to susceptible white pine as a function of density of upland* Ribes

Area	Planting date	Infection measured: Year	Infection measured: Percent	Upland *Ribes* density
Skull Creek	1971	1975	>75	High
Priest River - middle elevation	1971	1977	>80	High
Ida Creek	1971	1977	< 5	Low
West Fork Merry Creek	1969	1976	>90	High
Gletty Creek	1969	1977	< 1	Low
Jaype	1970	1976	< 1	Low

The situation is not as simple as it appears. If we can assess hazard by some means of *Ribes* distribution mapping and site description, then I believe large areas of land would become available for planting easily obtained low-level resistant white pine. There is also the possibility that *Ribes* eradication could be used to advantage before planting or just after a regeneration cut. It could also be used to reduce damage to an acceptable level in certain stands already naturally regenerated. The time has come to take a new look at *Ribes* eradication.

How can one manage stands of low-level resistance to minimize losses? The third solution is to couple breeding for rapid growth with fertilization and other cultural techniques to *obtain rapid growth so that trees will pass through their most vulnerable stage quickly*. Trees are most vulnerable to damage during their early years while they are small. For example, if a stand growing on site class 60 was given one severe inoculation at 10 years of age, then 37 percent of the trees would be dead by age 35 years. If the stand was given the same inoculum load at age 25 years, 3 percent would be dead at age 50 years. This prediction by the simulator is based on the relationship of mortality to size, not age related variation in resistance. Also fast-growing trees apparently can "outgrow" the rust, which means a reduced level of mortality over a longer time span. Trees growing on a site with an index of 90 and given the inoculum load at age 25 are expected to show about 1.5 percent mortality by age 60, rather than 3 percent mortality at age 50 years as on a site indexed at 60. The assumption was made, in the absence of data to the contrary, that fungus growth rate is independent of tree growth rate.

If unexpectedly high levels of lethal infection are obtained such as would occur from a heavy inoculum year when a stand was young, then the fourth solution, *branch canker pruning*, is a possiblity. The major deterrent to this possibility is bole cankers resulting from infection of needles located on the bole. Fortunately, such infections are rare except at the highest infection levels because of the relatively small target such needles present. At 1,000 *R. viscosissimum* bushes/ha from age 15 to 20, about 150 trees/ha (original stand 2,000/ha) would have direct stem cankers. At 100 bushes (*R. viscosissimum*)/ha, less than 10 trees would have stem cankers. Since low-level resistance stock will be planted only on sites characterized by low *Ribes* populations, high densities of bushes (above 100/ha) should not be reached. Consequently, pruning of branch cankers should be a good backup solution in plantations and a reasonable alternative in some naturally regenerated stands, especially if used in conjunction with *Ribes* eradication.

There are still other combinations of resistance mechanisms, cultural treatments, biological controls, and chemical controls. The possibilities range from computer-assisted hazard prognosis to the incorporation of a biological control agent such as *Tuberculina maxima* (Wicker 1970), and the encouragement of natural inactivation of cankers (Hungerford 1977). An excellent opportunity exists for the development of an effective integrated control strategy that directs all management options toward a common goal--healthy and fast-growing western white pine.

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SUCKER REGENERATION IN A UTAH ASPEN CLONE AFTER CLEARCUTTING, PARTIAL CUTTING, SCARIFICATION, AND GIRDLING

George A. Schier and Arthur D. Smith[1]

ABSTRACT

Clearcutting, partial cutting, scarification, and girdling were used to stimulate root suckering in a Utah aspen clone. Regeneration was inventoried yearly during the first 4 years after treatment and again after 12 years. Clearcutting resulted in the greatest number of suckers. In most years, partial cuts (cuts that removed 67 percent of the basal area) had less than 50 percent as much regeneration as the clearcut plots. Girdling stimulated suckering to a lesser degree than cutting. Mortality was high on girdled plots and by the 12th year after treatment few suckers had survived. Scarification had no apparent effect on sucker production.

KEYWORDS: *Populus tremuloides*, aspen, root suckers, adventitious shoots, clearcutting, selection cutting, girdling

[1]The authors are, respectively, Plant Physiologist, located at the Intermountain Station's Forestry Sciences Laboratory, Logan, Utah, and Professor Emeritus, Department of Range Science, Utah State University, Logan.

Little information is available for the Rocky Mountains that pertains to methods of regenerating aspen (*Populus tremuloides* Michx.). Practically all aspen regeneration in the West is by root suckering. Methods to induce suckering are needed in areas where aspen clones are not regenerating and where it is desirable to maintain the species.

Baker (1969) and Smith and others (1972) reported the effect of cutting, girdling, and scarification on regeneration in a Utah aspen clone. They made yearly inventories of sucker numbers for 4 consecutive years after treatment. In the 12th year, we determined the condition of the aspen regeneration. Our findings are presented here.

ORIGINAL STUDY 1965-1969

Methods

The aspen clone used in this study is in the Twin Creek drainage of the Wasatch Mountains approximately 20 miles (32 km) northeast of Logan, Utah. Mean elevation of the site is 7,850 ft (2,390 m). The site has a southeast aspect and a deep sandy loam soil formed from Wasatch conglomerate.

The clone occupies approximately 21 acre (8.5 ha). When treatments were applied in 1965, the stand was approximately 55 years old and had a 130 ft^2/acre (30 m^2/ha) basal area. At that time, the average height and the diameter breast height (d.b.h.) of codominant trees was 58 ft (18 m) and 8 inches (20 cm), respectively.

Fifteen plots, 175 x 175 ft (53.3 x 53.3 m), were laid out in the clone and each of the five following treatments randomly assigned to three:

1. Clearcut--felled trees limbed, cut into logs, and logs piled along the plot boundary.

2. Partial cut--stems of large diameter removed leaving a basal area of 41.2 ft^2/acre (9.46 m^2/ha), 33 percent of the original basal area. Felled trees limbed and left where they lay.

3. Girdled--done with a hand ax.

4. Scarified--ripper blade drawn over plots at 6 to 10 ft (1.8 to 3.0 m) intervals and at depths varying from 3 to 8 inches (7.6 to 20.3 cm).

5. Control.

Treatments were started June 26, 1965, and were completed August 12, 1965.

Results

Clearcutting resulted in the greatest number of aspen suckers (table 1). The partially cut plots had 47 percent as much regeneration as the clearcut plots by the 4th year after treatment. The girdled aspen took 1 to 3 years to die. Girdling stimulated regeneration, but mortality was high, and by the fourth year only 6 percent of the initial numbers of suckers remained. The scarified plots did not produce significantly more suckers than the controls and therefore were not inventoried in 1977.

Table 1.--*Sucker regeneration in the* [illegible] *the first 4* [illegible] *others 1972)*

Treatment	Year after treatment: First	Second	Third	Fourth
	Suckers per acre (ha)			
Clearcut	52,332 (129,312)a[1]	24,040 (59,403)a	20,809 (51,41[illegible])	13,[illegible]00 (32,617)
Partialy cut	22,053 (54,493)ab	11,660 (28,812)a	12,232 (30,22[illegible])	6,173 (15,253)
Girdling	13,038 (32,217)b	4,047 (10,000)ab	2,808 (6,939)	773 (1,910)
Scarification	5,022 (12,409)b	1,880 (4,645)b	3,805 (9,402)	2,253 (5,567)
Control	3,447 (8,518)b	3,466 (8,564)b	4,140 (10,230)	2,400 (5,930)

[1]Treatments with no common letters are significantly different at the 5 percent level.

1977 INVENTORY

Methods

Aspen regeneration on each clearcut, partially cut, girdled, and control plot was sampled using 25 107.6 ft^2 (10 m^2) circular subplots with plot centers at a spacing of 25 x 25 ft (7.62 x 7.62 m). A uniform buffer zone, 30.2 ft (9.2 m) in width, around the area sampled in each plot reduced boundary effects. Suckers were divided into height classes, smaller that 3.28 ft (1 m), and 3.28 ft and larger. In each of the clearcut and partially cut plots, total heights of 20 randomly selected dominant and codominant saplings were measured.

Numbers and d.b.h. of mature stems on each partially cut and control plot were obtained from four randomly located 1,076.2 ft^2 (100 m^2) circular plots. Five dominant and codominant trees were randomly selected on each control plot for height determination.

Results

Descriptions of the mature stems (mean age 67 years) on control and partial cut plots are given in table 2. Mean height of the dominant and codominant trees on the control plots was 69 ft (21.0 m).

Table 2.--*Description of mature stems (mean age, 67 years) on control and partially cut plots in the Twin Creek aspen clone in 1977, 12 years after treatment*

Treatment	d.b.h. in (cm)	Stems per acre (ha)	Basal Area ft^2/acre (m^2/ha)
Control	8.2 (20.8)	367 (908)	140.1 (32.17)
Partial cut	8.9 (22.5)	121 (300)	51.6 (11.48)

The largest number and greatest frequency of suckers in the <3.28 ft (1 m) size class occurred on the control plots (table 3). Most of these were less than 4 inches (10.16 cm) in height, and many had arisen during the previous growing season. The mortality rate in this size class was high. The partially cut plots also had large numbers of smaller suckers, but the clearcut and girdled plots had relatively few.

Table 3.--*Number and frequency of sucker regeneration in treated plots of the Twin Creek aspen clone in 1977, 12 years after treatment*

Treatment	Regeneration			
	Number		Frequency	
	<1 m	>1 m	<1 m	>1 m
	Suckers per acre (ha)		*Percent*	*Percent*
Clearcut	11 (27)c[1]	5,795 (14,320)a	3	100
Partialy cut	831 (2,053)b	2,284 (5,643)b	39	97
Girdled	16 (40)c	124 (307)c	3	15
Control	2,272 (5,613)a	313 (773)c	73	27

[1]Treatments with no common letters are significantly different at the 5 percent level.

The effect of treatment in 1965 on aspen regeneration was best shown by the number and frequency of suckers 3.28 ft (1 m) and larger (table 3). Sapling size suckers were most plentiful on the clearcut plots. When overstory trees were left in the partial cuttings, sucker numbers were reduced 60 percent. The girdled plots had even fewer suckers than the control plots (fig. 1).

Dominant and codominant suckers were significantly (1 percent level) taller on the clearcut than on the partially cut plots. Mean sucker heights were 19.3 ft (5.87 m) on the clearcut plots and 16.0 ft (4.89 m) on the partially cut plots.

DISCUSSION

The large numbers of small aspen suckers in the control plots indicate that it is normal for suckers to arise regularly in an aspen clone. Baker (1925) made a similar observation. While a clone is reasonably well stocked, the suckers are generally weak, inconspicuous, and do not live long. When the canopy opens because of natural mortality, additional light increases sucker survival and growth.

As in most studies on the effect of cutting methods on aspen regeneration (Brinkman and Roe 1975; Jones 1976; Sampson 1919; Sandberg 1951), the clearcut plots produced the largest number of suckers. Generally, after logging, sucker numbers are directly related to the number of stems removed; the greater the number of stems cut, the greater the proportion of root system that produces suckers. Suckers on partially cut plots grow more slowly than suckers on clearcut plots because of competition and shade provided by remaining trees. If as little as 10 to 15 ft^2/acre of (2.30 to 3.44 m2/ha) of basal area of residual overstory is left after cutting Eastern aspen, sucker growth will be substantially reduced (Perala 1977).

Girdling appears to be a good method for eliminating aspen from a site. Westveld (1939), apparently referring to unpublished data from the Lake States, reported that girdled aspen produce few suckers. Regeneration of girdled plots was unsuccessful because of a relatively poor initial response to treatment and high mortality in subsequent years. Suckers arose from roots of girdled aspen because the downward flow of auxin inhibitors in the phloem was stopped (Schier 1978); however, far fewer suckers were produced than from roots of decapitated trees because growth-promoting hormones that are synthesized in the roots do not accumulate but continue to move up the stem in the xylem. High sucker mortality was probably caused by the rapid deterioration of roots on girdled trees. Root dieback occurred because the tops, which remained alive for 1 to 3 years after treatment, drained the roots of food reserves and other growth factors. Of course, photosynthates, which are manufactured in the crowns, could not be translocated to the roots of girdled trees. Shade cast by girdled trees after treatment also contributed to sucker mortality by creating a microenvironment unsuitable for sucker development and growth.

Figure 1.--One of the girdled plots in September 1977 with a clearcut plot in the background. A typical dead girdled stem is lying on the ground in the foreground. The tree fell because of basal root breakage. Widespread occurrence of root breakage indicated general decay of the root systems on girdled plots.

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CHILLING REQUIREMENTS FOR OPTIMAL GROWTH OF ROCKY MOUNTAIN DOUGLAS-FIR SEEDLINGS

S. P. Wells[1]

ABSTRACT

*One-year-old Douglas-fir (*Pseudotsuga menziesii *var.* glauca*) seedlings from three contrasting interior provenances were chilled for periods ranging from 2 to 20 weeks. Chilling treatments were: a constant 4°C, a fluctuating 4°C night and 10°C day, and the outdoor environment. Analyses of six variables related to growth and phenology suggest that the chilling requirements of Rocky Mountain Douglas-fir seedlings were best satisfied by 17 weeks of constant 4°C.*

KEYWORDS: Douglas-fir, chilling requirement, chilling period

In the fall, woody plants of temperate climates undergo physiological changes that provide resistance to cold during the winter. The internal changes prevent growth until the plant has been exposed to cool temperatures. The range and duration of exposure to cool temperatures required before growth can resume is the "chilling requirement." The chilling requirements of numerous conifers have already been assessed: *Pseudotsuga menziesii* var. *menziesii* (Wommack 1964; Lavender and Hermann 1970; Campbell and Sugano 1975; van den Driessche 1975), *Pinus strobus* (Berry 1965), *Pinus monticola* (Steinhoff and Hoff 1972), *Picea abies* (Worrall and Mergen 1967; Dormling and others 1968), and seven species of *Picea* (Nienstaedt 1966, 1967).

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In general, 3°-6°C is the most effective chilling temperature for most species. However, species vary greatly in the duration of required chilling. For example, 4 weeks is required for *Picea abies* (Dormling and others 1968) while 16 weeks is required for *Pinus monticola* (Steinhoff and Hoff 1972).

In the Northern Rocky Mountains, Douglas-fir (*P. menziesii* var. *glauca*) seedlings are being container-grown in greenhouses, shadehouses, and growth chambers for both reforestation and research. Although the coastal Douglas-fir (*P. menziesii* var. *menziesii*) requires a chilling period of 8-12 weeks at 3°-6°C (Wommack 1964; Lavender and Hermann 1970; Campbell and Sugano 1975; van den Driessche 1975), information on the chilling requirements of the Rocky Mountain variety is lacking. Yet, in order to obtain optimal growth from container-grown seedlings, the chilling requirement must be known.

The primary objective of the study reported here was to determine the chilling requirement of Rocky Mountain Douglas-fir seedlings in both a controlled environment and the outdoor environment. A secondary objective was to detect possible differences in chilling requirements among provenances. For this study, the chilling requirement was considered satisfied when additional chilling resulted in no increase in growth.

MATERIAL AND METHODS

Two separate experiments were established. Both used seed from three ecologically and geographically contrasting provenances (table 1). For each provenance, 60-75 seed were sown in each of eighteen 8-inch (20-cm) pots. After the seed had germinated in the greenhouse, all seedlings (approximately 50 per pot) were moved to a shadehouse to complete their first year of growth. After bud set and following the first hard frost (below -3°C), which occurred October 17, studies of the chilling requirements were begun.

Experiment I.--To determine the amount of chilling required for seedlings in the outdoor environment, six pots of seedlings from each provenance were placed under a bench in the lathhouse and were mulched with sawdust. One pot of seedlings from each provenance was moved into the greenhouse after 2, 8, 11, 14, 17, and 20 weeks. A continuous temperature record was obtained by placing a hygrothermograph with the seedlings (fig. 1).

Experiment II.--The second experiment was designed to assess chilling period requirements of seedlings under two temperature regimes:

Treatment 1. 4°C constant with moderate light (300 ft-c; 3,230 lux) for 8 hours per day.

Treatment 2. 10°C, 8-hour day with moderate light (300 ft-c; 3,230 lux) and 4°C, 16-hour night.

For each treatment, six pots of seedlings from each provenance were placed in a "holding" chamber set for a 16°C 10-hour day and a 10°C 14-hour night. These settings were used to keep the seedlings at the first stage or dormant-quiescent stage of acclimation (Weiser 1970) without providing chilling. For each treatment, one pot of seedlings from each provenance was taken from the "holding" chamber and placed into a chilling chamber at intervals that provided 2, 8, 11, 14, 17, and 20 weeks of chilling at the end of 20 weeks. Although seedlings spent a variable amount of time in the "holding" chamber, the end of the chilling treatment occurred on the same date for all seedlings. Consequently, effects of the treatments on growth and development of the seedlings could be observed under uniform conditions.

Table 1.--*Provenances of Rocky Mountain Douglas-fir represented in chilling study*

Provenance No.	Latitude	Longitude	Elevation	National Forest	Habitat type
			Meters		
4	45°50'	115°55'	1,060	Nezperce	*Abies grandis/ Pachistima myrsinites*
18	48°35'	118°35'	1,430	Colville	*Abies lasiocarpa/ Pachistima myrsinites*
22	48°21'	117°15'	885	Colville	*Thuja plicata/ Pachistima myrsinites*

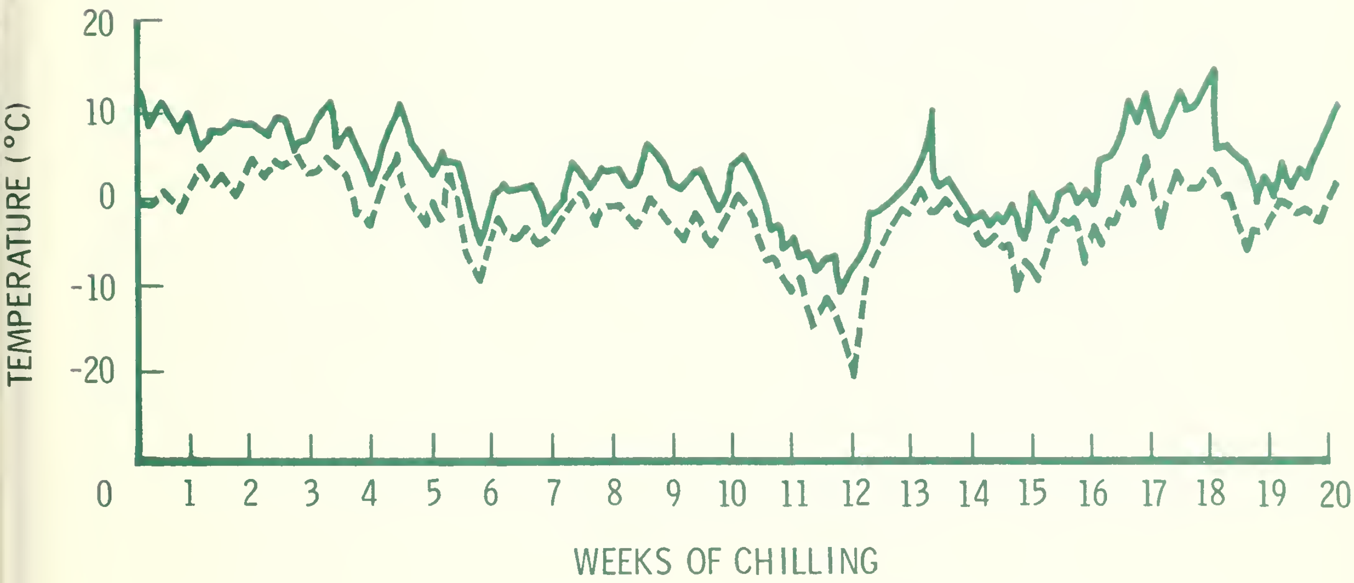

Figure 1.--Daily maximum and minimum temperatures recorded by hygrothermograph during outdoor chilling of seedlings in Experiment I.

In both experiments, chilled seedlings were moved to a greenhouse maintained at 21°-24°C, with a 14-hour photoperiod of sunlight extended with a combination of fluorescent and incandescent lighting. All seedlings were checked twice weekly and the following data taken on individual seedlings: number of days to terminal bud burst, number of days to formation of the first terminal bud, total height, and epicotyl elongation.

Analyses of variance were used to assess the chilling requirement of each provenance. These analyses were based on the means of all seedlings within a pot for: total height, amount of elongation, days to bud burst and bud set, duration of growth, and deviation from predicted growth. The last variable was the deviation from regression of total height on first-year height. As such, it represents rate of growth from a constant initial height.

RESULTS

Although no statistical comparisons could be made between the two experiments, differences were obvious. Only 75 percent of the seedlings in Experiment I burst bud, whereas 90 percent of the seedlings in Experiment II burst bud. Secondly, seedlings in Experiment 1 averaged 0.24 cm shorter, 2-1/2 days later in bud burst, 9 days later in bud set, and 6-1/2 days longer in duration of growth. Generally, the outdoor environment provided less effective conditions for satisfying chilling requirements than the chilling chambers.

Experiment I.--Duration of chilling period had a pronounced effect on the percentage of seedlings which burst terminal bud (fig. 2). Analysis of variance showed that chilling periods had significant effects on only bud burst, bud set, and deviation from the regression of final height on initial height (table 2A). Effects of chilling period are evident in the mean values associated with increasing duration of chilling period (table 2B). The longer the chilling period, the earlier bud burst and bud set and the greater the growth from a constant initial height.

Main effects of provenances were significant for date of bud burst, date of bud set, total height, and shoot elongation. On the average, seedlings from provenance 18 burst bud 3 days later and set bud 4 days later than seedlings from the other two provenances. Even though provenances differed in total height and elongation, it is noteworthy that these differences were entirely the result of first-year growth. When total height was adjusted for first-year height, no differences could be detected among provenances.

Experiment II.--Chilling temperature significantly affected bud burst and duration of growth (table 3A). Seedlings chilled at 4°C constant temperature burst bud about 2 days earlier and grew about 1-1/2 days longer than those chilled at 4°-10°C fluctuating temperature. Yet in general, few differences were obvious between treatments.

Increases in duration of chilling period up to 17 weeks resulted in earlier bud burst and progressive increases in growth (table 3; fig. 3). After 17 weeks of chilling, little effect of an increased chilling period was evident.

Effects of provenances were significant for several variables. These effects paralleled those detailed for Experiment 1. In general, interactions involving provenances were insignificant. This suggests that chilling requirements are similar for all provenances tested.

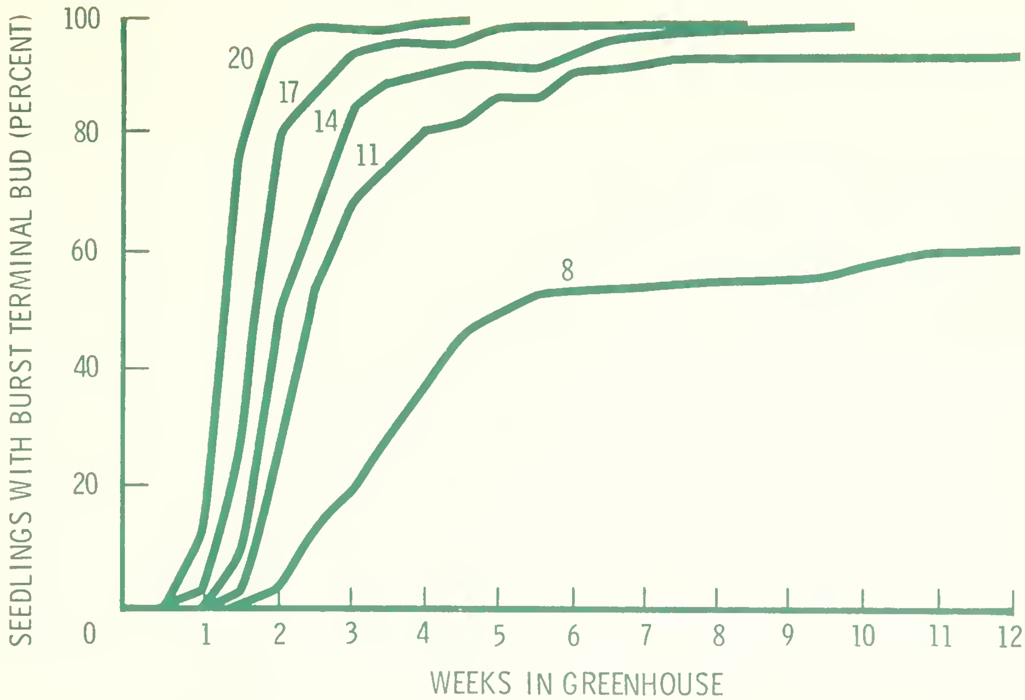

Figure 2.--Experiment I (lathhouse) - relationship between cumulative percentage of seedlings that burst terminal bud and weeks in greenhouse for various chilling periods.

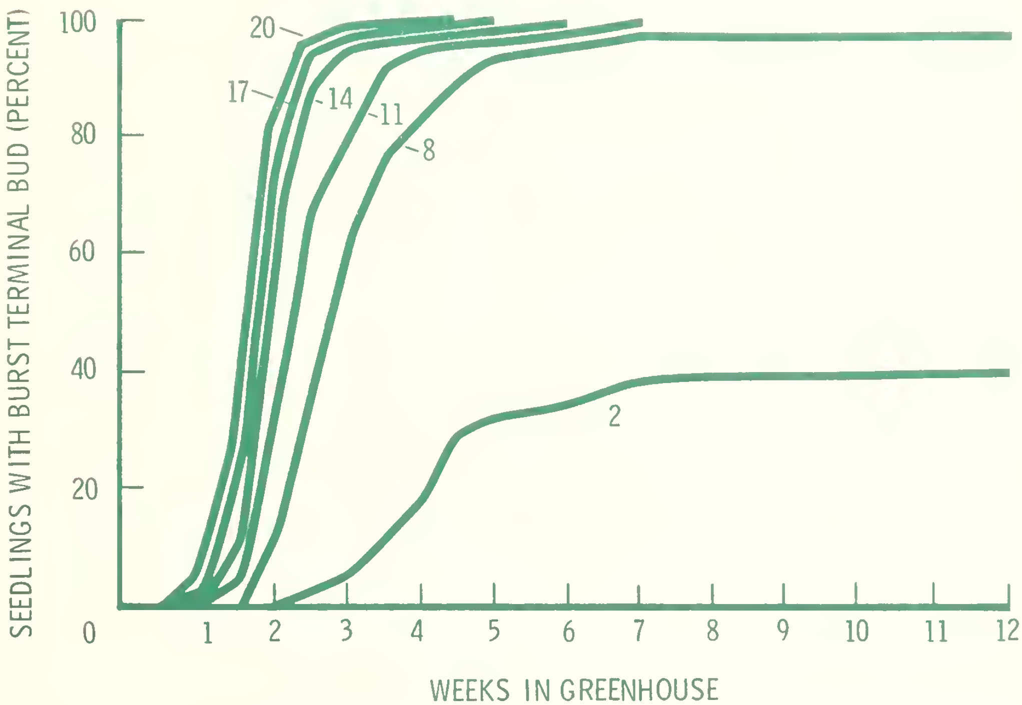

Figure 3.--Experiment II (growth chambers) - relationship between cumulative percentage of seedlings that burst terminal bud and weeks in greenhouse for various chilling periods.

Table 2.--*Results of Experiment I. Part A: Analysis of variance. Part B: Mean values of six variables according to chilling period*

A.

Source of variation	Degrees of freedom	Total height	Elongation	Deviation from predicted growth	Bud burst	Bud set	Duration of growth
Provenance	2	**	**	NS	**	*	NS
Chilling period	4	NS	NS	**	**	**	NS
Provenance X Chilling period	8						

* Denotes significance at the 0.95 level of probability.
** Denotes significance at the 0.99 level of probability.

B.

Chilling period	Total height	Elongation	Deviation from predicted growth	Bud burst	Bud set	Duration of growth
Weeks	*Centimeters*			*Days*		
2	Only one seedling burst bud					
8	7.76	2.84	-0.81	30.3	52.7	22.4
11	8.66	3.69	.02	21.6	47.6	26.0
14	8.27	3.60	.12	18.8	41.4	22.6
17	8.35	3.60	.16	14.8	39.7	24.9
20	8.46	3.92	.51	10.9	33.1	22.2

DISCUSSION

Results of this study describe the chilling requirements of seedlings from three provenances. Data on growth and phenology were obtained from the first period of shoot elongation during the second growing season. However, seedlings usually flush and set terminal bud two or three times during the second growing season under optimal conditions. But, because the first flush of growth is from a preformed bud and subsequent flushes are from buds developed during the current growing season, chilling directly affects only the first flush.

Results of Experiment I showed that an increase in chilling period was accompanied by progressive changes in three variables: elongation, date of bud burst, and growth. This suggests that for the year tested, 20 weeks of chilling in the natural environment may have been insufficient for realizing the maximum growth potential of the seedlings tested. However, a comparison of mean response of seedlings to 20 weeks of chilling in Experiment I with those of a comparable chilling period in Experiment II suggests that 20 weeks of chilling in the natural environment was very close to being optimal.

A 20-week chilling period represents the requirement of seedlings for only one winter at Moscow, Idaho. The controlled environment experiments had warmer average temperatures and the optimum chilling period was 17 weeks. Therefore, it seems that 20 weeks of chilling should be considered maximum for most Rocky Mountain environments.

Table 3.--*Results of Experiment II. Part A: Analysis of variance for Experiment II. Part B: Mean values of six variables according to chilling periods*

A.

Source of variation	Degrees of freedom	Total height	Elongation	Deviation from predicted growth	Bud burst	Bud set	Duration of growth
Treatment	1	NS	NS	NS	**	NS	*
Provenance	2	**	**	NS	**	**	*
Chilling period	5	NS	**	**	**	**	**
Treatment X Provenance	2	NS	NS	*	NS	NS	NS
Treatment X Chilling period	5	NS	NS	NS	NS	NS	NS
Provenance X chilling period	10	NS	NS	NS	*	NS	NS
Treatment X Provenance X Chilling period	10						

* Denotes significance at the 0.95 level of probability.
** Denotes significance at the 0.99 level of probability.

B.

Chilling period	Total height	Elongation	Deviation from predicted growth	Bud burst	Bud set	Duration of growth
Weeks	*Centimeters*			*Days*		
2	8.61	2.94	-1.27	31.7	43.2	11.5
8	8.97	3.71	-0.25	22.1	38.6	16.5
11	8.71	3.83	.11	18.3	36.1	17.8
14	9.06	4.00	.17	15.5	32.1	16.6
17	9.26	4.43	.73	14.2	32.6	18.4
20	9.16	4.25	.51	13.6	31.0	17.4

In Experiment II, bud burst occurred progressively earlier with an increase in duration of chilling period. However, variables related to growth potential culminated at about 17 weeks of chilling. As suggested by Campbell and Sugano (1970), bud burst may not culminate with increased chilling, but the range of temperatures at which growth begins may increase to the point that growth begins at chilling temperatures. Consequently, optimal growth should be the main criterion by which effectiveness of chilling treatments is measured. Therefore, the results of Experiment II suggest that 17 weeks of chilling at 4°C constant temperature best satisfied the chilling requirement of the Rocky Mountain Douglas-fir seedlings tested.

These results are in general agreement with the findings of van den Driessche (1975). He concluded that 15 weeks of chilling at 4.4°C fulfilled the chilling requirements for seedlings from a single interior British Columbia provenance of Douglas-fir.

Results of analyses of variance suggested that the provenances tested required a similar chilling duration. Although seedlings from provenance 18 performed very differently from those from the other two provenances, analysis failed to detect interactions involving provenances. However, these analyses included data from only those seedlings that had burst bud. When provenances are compared according to the percentage of seedlings that had burst bud in all treatments of both experiments, provenances differ significantly (0.95 level of probability). Altogether, 87 percent of the seedlings from provenances 4 and 22 burst bud, but only 80 percent of those from provenance 18 burst bud. Moreover, these differences were consistent in both experiments. As a consequence, it seems that the major difference between the provenances tested is in the number of seedlings which had their chilling requirements satisfied by a given chilling treatment rather than in performance subsequent to bud burst.

CONCLUSIONS

From the findings of this study, the following recommendations can be made concerning chilling requirement of Rocky Mountain Douglas-fir seedlings: First, if chilling is done in an outdoor environment similar to Moscow's, 20 weeks of chilling are recommended after the first hard frost. Second, at least 17 weeks of chilling at 4°C is recommended in controlled environments.

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PATTERNS OF FIRST-YEAR GROWTH IN POPULATIONS OF DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* VAR. *GLAUCA*)

Gerald E. Rehfeldt[1]

ABSTRACT

One-year-old seedlings representing 56 populations of Douglas-fir from the Inland Northwest expressed variation in patterns of growth. Population means for the percentage of seedlings with a single period of epicotyl elongation varied from 1 percent to 81 percent. A multiple regression of the percentage of seedlings with one growth period on geographic and ecologic variables of the seed source accounted for 40 percent of the variation in the dependent variable.

KEYWORDS: ecological genetics; Rocky Mountain Douglas-fir; seed zoning; geographical variation; growth patterns.

Seed zones are based on variation in numerous traits that reflect adaptation to the natural environment. For Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in the Northern Rocky Mountains, variation in growth, phenology, and freezing tolerance reflects adaptations to three relatively distinct environmental provinces: (1) northern Idaho and northeastern Washington, (2) western Montana, and (3) relatively cool environments regardless of geography (Rehfeldt 1978).

Current research is assessing adaptation of populations within the northern Idaho province, which is bounded by the Columbia River in northeastern Washington, the Salmon River in northern Idaho, and the state line between Idaho and Montana. Within this province populations of greatest cold hardiness in early autumn tend to be from high latitudes, high elevations, and subalpine habitat types (Rehfeldt in press).

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

The present study was begun to determine if populations of Douglas-fir differ in their ability to tolerate drought, and to incorporate variation in drought resistance into seed zones for northern Idaho. One-year-old seedlings were exposed to moisture stresses by withholding water. However, all variation among populations in ability to endure the imposed stress was explained by the proportion of seedlings from each population that had either one or two periods of shoot elongation. But since the end of the first period of elongation or the beginning of the second period occurred before seedlings were subjected to the moisture stress, the data only reflected variation in the pattern of first-year growth.

METHODS

Patterns of growth were observed in 1-year-old seedlings representing 56 populations from the Inland Northwest (fig. 1). Most of these populations were from the northern Idaho environmental province, but populations from the following peripheral areas were also included: northeastern Oregon, north central Washington, central Idaho, and Montana east of the Cabinet Divide.

Populations from the northern Idaho province were selected from the five habitat types (Daubenmire and Daubenmire 1968) on which Douglas-fir is most common. However, few populations were selected from the *Abies lasiocarpa* series of habitats; adaptive differentiation has already been associated with the cool environments of these habitat types (Rehfeldt 1978). In addition, an attempt was made to reduce confounding among the latitudes, longitudes, elevations, and habitat types represented by populations from northern Idaho. Interrelationships among these variables are expressed in the following matrix of correlation coefficients:

	Interclass Correlations		*Intraclass correlations*
Variable	*Longitude*	*Elevation*	*Habitat type*
Latitude	0.67**	-0.22	0.12
Longitude		-.35*	.01
Elevation			.23*

*Statistical significance at the 0.05 level of probability.
**Statistical significance at the 0.01 level of probability.

The strong correlation between the latitude and longitude of population origin reflects the physical shape of northern Idaho (fig. 1). Habitat types accounted for 23 percent of the variance in elevation of the populations reflecting a general altitudinal distribution of habitat types (Daubenmire and Daubenmire 1968).

For each of two replications of a randomized complete block design, 21 seedlings from each population were grown in plastic containers (150 cm^3). Seeds were sown in early May, and seedlings were grown in a greenhouse under natural day length and optimal levels of moisture until late June, when the containers were watered until soil moisture reached saturation. No additional water was added for the remainder of the study. Greenhouse temperatures ranged from 27° to 38°C during the day and from 10° to 16°C during the night. For each seedling, the date the germinated seed emerged was recorded and the number of periods (1 or 2) of epicotyl elongation scored.

In order to assess adaptive differentiation of populations, an analysis of variance was made on the proportion of seedlings that exhibited a single period of growth. Multiple regression analyses were made to relate mean performance of populations to geographic and ecologic criteria of the seed source. The following model was used:

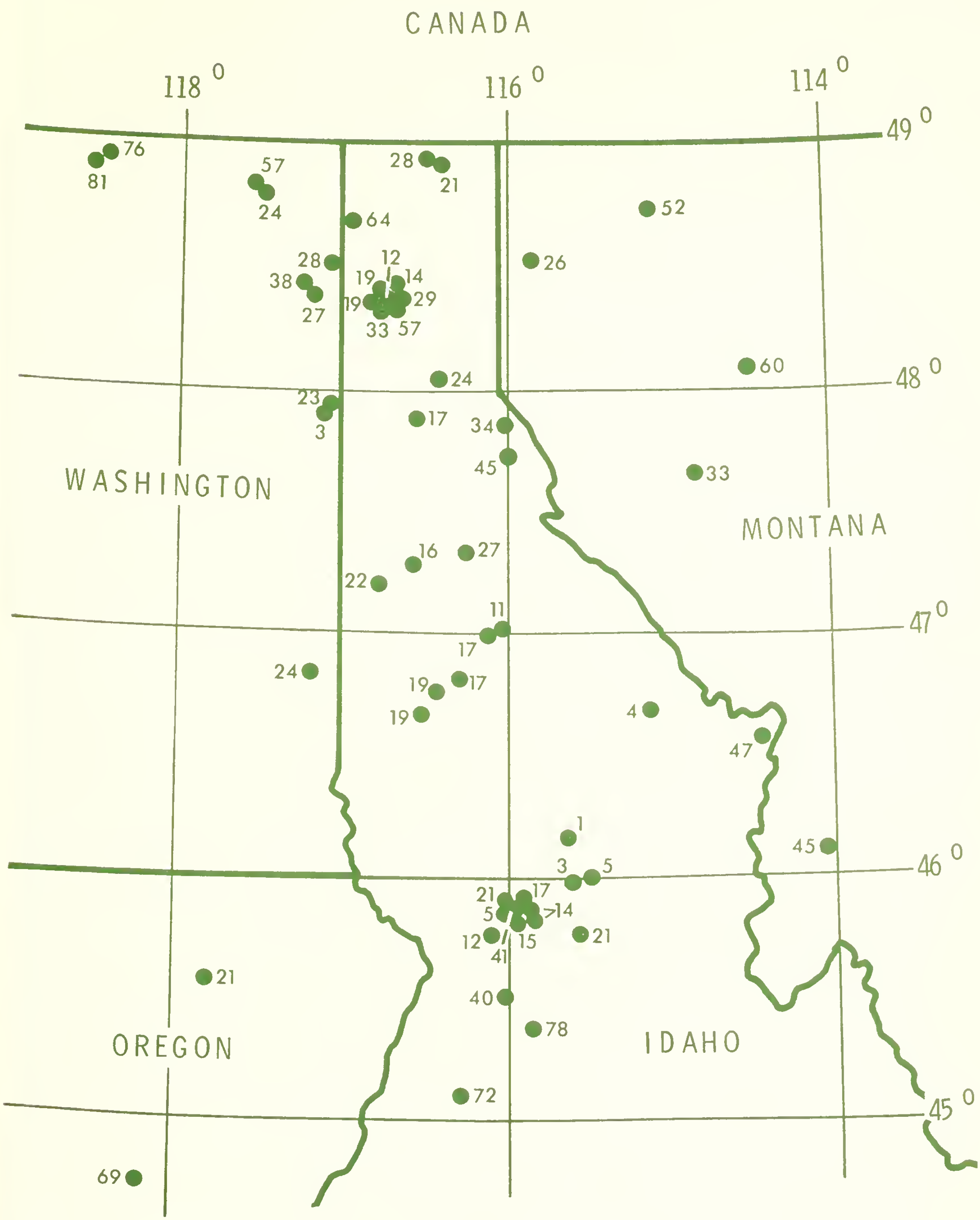

FIGURE CAPTION

Figure 1.--Location of populations (dots) and mean percentage (numbers) of seedlings with a single period of first-year elongation.

$$Y_i = b_0 + b_1 X_{i1} + \ldots b_7 X_{i7}$$

where:

Y_i = proportion of seedlings from population i that had one period of growth.

X_{i1} = degrees latitude at the origin of population i.

X_{i2} = degrees longitude at the origin of population i.

X_{i3} = meters ($\times 10^{-2}$) elevation at the origin of population i.

X_{i4} to X_{i7} = constant terms that respectively code the *Pseudotsuga menziesii*, *Abies grandis*, *Thuja occidentalis*, and *Tsuga heterophylla* habitat types.

Under this model, effects of the *Abies lasiocarpa* habitat types are included in the intercept (b_0), which also includes the general mean. Regression coefficients for constant terms are deviations from b_0 that reflect effects of particular habitat types.

RESULTS AND DISCUSSION

Near the end of June, 1-1/2 months after seeds were sown, seedlings began to form terminal buds. Only 71 percent of the seedlings resumed growth. Since containers were last watered near the end of the first period of elongation, the pattern of growth was not influenced by moisture stress. Mortality from moisture stress did not begin until mid-August, 1-1/2 months after the final watering.

Seedlings with only a single period of epicotyl elongation averaged 15 mm shorter than those with two periods, even though the growing season was curtailed by moisture stress; moreover, the pattern of growth did not seem to be related to the date of emergence. Although emergence took place over an interval of 15 days, the mean day of emergence for seedlings with one or two periods of growth was 17.6 and 18.2 days after sowing, respectively.

Individual populations were characterized by as little as 1 percent and as much as 81 percent seedlings that had only one period of shoot elongation (fig. 1). That mean differences are real is suggested by the following analysis of variance:

Source of variation	*df*	*Intraclass correlation*	*Level of significance of F-value*
Replications	1	0.02	5%
Populations	55	.77	1%
Rep. x Pop.	55	.21	--

Since the primary objective of the study was to assess adaptive differentiation of populations from the environmental province that includes northern Idaho and eastern Washington, populations from peripheral areas were excluded from multiple regression analyses. Peripheral populations likely represent contrasting environmental provinces (Wright and others 1971; Rehfeldt 1978) for which multivariate relationships differ from those of the northern Idaho province.

The multiple regression analysis was significant at the 1 percent level of probability and accounted for 40 percent of the variation in the dependent variable. Differences between observed values and those predicted by the regression model were examined to ensure that error variances were homogeneous and that there was no visual evidence of lack of fit of data to the equation. Standarized partial regression coefficients (b') for the independent variables are:

	Variable	*b'*
Y_1	latitude	0.32
Y_2	longitude	.17
Y_3	elevation	.29
	habitat type:	
Y_4	*Pseudotsuga menziesii*	-.20
Y_5	*Abies grandis*	-.21
Y_6	*Thuja occidentalis*	-.23
Y_7	*Tsuga heterophylla*	.18

Standardized partial regression coefficients, which depict the relative influence of the independent variables in determining the dependent variable, indicate that latitude and elevation are major determinants of pattern of first-year growth in populations from north Idaho. Latitude and elevation are related to the dependent variable by statistically significant (1 percent level) simple correlation coefficients of 0.47 and 0.43, respectively.

In addition, the regression statistics also suggest that habitat types were influential. In fact, habitat types alone accounted for 23 percent of the variation among populations; and the associated F-value was significant at the 5 percent level of probability. Mean values for Idaho populations from the five habitat types were:

Habitat series	*Number of populations*	*Percentage seedlings with one growth period*
Pseudotsuga menziesii	10	20.7
Abies grandis	12	19.4
Thuja occidentalis	14	21.1
Tsuga heterophylla	5	35.5
Abies lasiocarpa	4	40.9

Since regression coefficients for constant terms reflect mean values, tests for differences among coefficients for the various habitat types are essentially tests for differences among the mean values listed above. Tests of "*t*" for differences in regression coefficients implied that the two greatest mean values differed significantly from the three lowest; however, previous results (Rehfeldt 1978; in press) make it doubtful that populations from the *Tsuga* habitat types are more similar genetically to populations from cold environments than to those from similar mesic environs. One of the five populations from a *Tsuga* habitat type represented the broad Priest Lake valley in northern Idaho. Much of the vegetation in this valley represents an ecotone between the *Tsuga* and *Abies lasiocarpa* series. This particular population was characterized by an unusually high proportion (64 percent) of seedlings with only one growth period. If this population is included in the subalpine series of habitat types, no differences can be detected among the *Pseudotsuga, Abies grandis, Thuja,* and *Tsuga* habitat types. Thus, it seems that the effects of habitat types in the regression analysis result primarily from the performance of seedlings from *Abies lasiocarpa* habitat types, which contrasts with that of seedlings from the other habitat types.

Multiple regression analyses account for average performance in relation to geographic and ecologic factors. Still, the performance of several individual populations should be mentioned. Populations from *Abies lasiocarpa* habitat types from two small frost pockets at 820 m and 950 m elevation did not express similar patterns of elongation and rates of cold acclimation (Rehfeldt 1978; in press) to populations from subalpine environments at relatively high elevations. Yet, seedlings representing a population from a large frost pocket in the Priest Lake valley, elevation 900 m, performed similarly to those from high elevations. Evidently, the genetic composition of trees occupying a frost pocket depends on the size of the pocket and availability of a suitable seed source as well as variation in environmental selection coefficients.

Populations from areas peripheral to the central area of study produced the following proportions of seedlings with one growth period:

Area of origin	*Number of populations*	*Percentage seedlings with one growth period*
Blue mountains, northeastern Oregon	2	43
Okanogan Mountains, northern Washington	2	78
Montana east of the Cabinet Divide	4	47
Central Idaho	3	63

Even when the elevation and habitat type of population origin are considered, populations from the peripheral areas were characterized by a much higher proportion of seedlings with only one growth period than populations from northern Idaho and northeastern Washington (fig. 1). As suggested previously (Wright and others 1971; Rehfeldt 1978), these peripheral populations likely represent environmental provinces of adaptational norms different from those of northern Idaho and eastern Washington.

Irgens-Moller (1968) and Sorensen[2] have also observed variation in patterns of growth in Rocky Mountain Douglas-fir. Consequently, variation among populations in patterns of growth does not seem to be an artifact induced by cultural conditions. Positive relationships were observed between the latitude or elevation of the seed source and the proportion of seedlings with a single period of growth. These results are similar to those involving variation in cold hardiness of Douglas-fir populations (Rehfeldt in press). In fact, 38 of the populations represented in the present study were also included in freezing tests for hardiness. That the pattern of growth is related to autumnal dormancy and thereby to the length of the growing season is suggested by the statistically significant (1 percent level) simple correlation ($r = 0.57$) relating measures of hardiness in early autumn to the proportion of seedlings that expressed a single growth period.

Because of the correspondence between current and previous results on variation of Douglas-fir populations from northern Idaho, practical implications of current data are similar to those based on variation in cold hardiness: seed zones for northern Idaho and eastern Washington should not encompass more than 1-1/2° latitude and 400 m elevation; and *Abies lasiocarpa* habitat types seem to represent a separate zone (Rehfeldt 1978; in press).

This study represents one of a series on the ecological genetics of Douglas-fir in the Northern Rocky Mountains. It has shown that populations are differentiated according to the pattern of first-year growth. At the present time, little is known about this trait, but if it is related to adaptive differentiation, the genetic and environmental controls of patterns of first-year growth need further study.

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SOME CHEMICAL CHARACTERISTICS OF GREEN AND DEAD LODGEPOLE PINE AND WESTERN WHITE PINE[1]

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ABSTRACT

The chemical components and combustion characteristics of dead and live lodgepole pine and western white pine were determined. Except for small variations, the chemical composition and burning characteristics of sound dead wood were nearly identical to the corresponding live wood for both species. Therefore, dead wood could be utilized as a source of chemicals, fuel, and as a substitute for live timber in the manufacture of wood products.

KEYWORDS: chemical components, combustion characteristics, dead trees, lodgepole pine, western white pine, utilization of dead trees

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[1] This report was prepared as a cooperative project of the Intermountain Forest and Range Experiment Station, Ogden, Utah, and the Wood Chemistry Laboratory, University of Montana, Missoula.

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INTRODUCTION

The Western United States, particularly the Northern Rocky Mountains, contains vast quantities of dead lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and western white pine (*Pinus monticola* Dougl.) trees. Unchecked insect and disease attacks are adding to the volume of dead timber. Although utilization of dead timber is gradually increasing as land managing agencies require its removal from sales areas, only a small percentage of the dead trees are being harvested and used. A recent survey, cited more than 7 billion board feet (about 28 million m^3) of dead timber in the Rocky Mountain States (Green and Setzer 1974). Furthermore, annual mortality is estimated to be 0.3 billion ft^3 (approximately 8.5 million m^3). The mortality rate will probably continue or possibly increase until the present overmature stands have been decimated or brought under management. The dead timber is thus a largely untapped reservoir of potentially utilizable material.

The principle deterrent to the use of dead timber is the lack of knowledge on the chemical, physical, and mechanical properties of this wood. The long exposure time under natural forest conditions may have adversely altered some of those desirable qualities present in green wood. This paper reports the results of chemical analyses for extractive content, cell wall components, and combustion characteristics of living and dead (standing and down) lodgepole pine and western white pine. The chemical characteristics of their "dead" wood were compared with the characteristics of "live" wood to determine the similarity and suitability for like products. Sample material was obtained from a single tree of each type for the two species.

Collecting and Testing Wood Samples

Lodgepole pine samples were obtained in June from trees on the Bitterroot National Forest, white pine samples in September from the Lolo National Forest. (Both Forests are in western Montana.) The selected trees one of each type, either green, dead down in contact with the ground, or dead standling, were approximately 8 inches (20.3 cm) in diameter. After felling, the trees were cut into short section, approximately 20 inches (50.8 cm) long and the sections were taken to the laboratory. Only sections with sound wood were taken from the Forest. At least 10 sections were obtained from each tree. The dead lodgepole pine had no bark whereas the dead white pine trees had retained the bark.

In the laboratory the sections were split longitudinally with an ax and the outer 1/2 inch (1.27 cm) (sapwood) was split off using a hammer and chisel. Sample material was also split off the heartwood portion of the chunks. These pieces were further reduced in size to approximately 3/8 by 3/8 by 5 inches (0.95 by 0.95 by 12.7 cm). The bark and cambium layers were peeled from the green tree pieces to prepare them for grinding.

The smaller size pieces were ground in a Wiley mill to pass through a 40-mesh screen. The identity of the sample material was retained throughout the preparatory process. A total of 12 samples were prepared, about 5 pounds (approximately 2.3 kg) in each. For each species, the samples were: green heartwood, green sapwood, dead standing heartwood, dead standing sapwood, down heartwood, and down sapwood. The ground samples were thoroughly mixed, stored in polyethylene bags, and refrigerated, to prevent the growth of mold and stain fungi, until required for analysis.

Samples of sapwood and heartwood of each wood type were used to determine moisture content and specific gravity. Moisture content (percentage) was determined by the ovendrying method and specific gravity was based on green volume-ovendry weight.

All chemical analyses were made in duplicate, and because of the small sample quantities, all weights were made to the nearest 0.0001 g. (Deviation of duplicated runs had to fall within 10 percent of their average value or the analysis was repeated until this criterion was met. For wood components constituting less than 3 percent of the raw wood, the criterion was expanded to 20 percent of the average value, and for materials less than 1 percent, it was expanded to 50 percent.) Where possible, analyses were made in accordance with procedures published by the American Society for Testing and Materials 1972. Ovendry weights of all sample materials and residues were used.

Ether and benzene-alcohol solubility determinations were made using 2-g samples of the unextracted wood (ASTM Standard Tests D1106-56 and D1107-56). The extractive results for all solvents were expressed as percentages of the original sample weights.

The hot water and caustic soda solubility determinations also used 2-g samples of unextracted wood. One hundred ml of distilled water and 100 ml of a 1 percent solution hydroxide (NaOH) were used in these extractions (ASTM Standard Tests D1110-56 and D1109-56).

The cell wall components were determined on an extractive free basis. The ground wood samples used in these analyses were successively extracted with benzene-alcohol (2:1, v/v), 95 percent ethyl alcohol, and hot water (ASTM Standard Test D1105-56).

A modified chlorite method was used to determine the holocellulose content (Browning 1967). Two grams of the extractive-free wood sample were delignified with sodium chlorite (200 g of sodium chlorite in 1 liter of water) and 40 ml of a buffer solution (60 ml of acetic acid and 1.3 g of sodium hydroxide in 1 liter of water) in a 250 ml Erlenmeyer flask. The delignification was carried out in a 75° ± 2°C water bath for 205 minutes with additions of 4 ml of the sodium chlorite solution at 0, 30, 60, 105, and 150 minutes. After 205 minutes, the digestion was stopped and the contents were washed into a gooch crucible with distilled water. Additional washings used acetone and distilled water. The white, fluffy residue, dried at 105°C, was termed holocellulose.

Alpha cellulose, that portion of holocellulose which is insoluble in 17.5 percent sodium hydroxide, was determined with 1-g samples of holocellulose as prepared above (ASTM Standard Test D1103-60).

Lignin is the residue or the portion of extractive-free wood that is insoluble in sulfuric acid (ASTM Standard Test D1106-56). Lignin residue in the holocellulose portion was determined by this same procedure and the value obtained was used to correct the results of the holocellulose and alpha cellulose determinations.

Hemicellulose was calculated as the difference between the lignin-residue-corrected original holocellulose weight and the final alpha cellulose weight.

A 2-g sample of unextracted wood was used to determine the ash content. The ash residue was expressed as a percentage of the original sample weight (ASTM Standard Test D1102-56).

The percentage of char was determined from a 1-g sample of unextracted wood placed in a preweighed dry aluminum foil pan. The sample was heated to 752°F (400°C) at a rate of 15°/minute under flowing nitrogen (200 ml per minute) in a tube furnace and was kept at this temperature for 10 minutes. The yield of char was weighed under nitrogen in a glove box, to prevent absorbtion of moisture.

The higher heating value of the char and of unextracted wood was determined in a Parr 1241 automatic adiabatic calorimeter. The heat value was expressed in megajoules per kilogram of ovendried wood.

Results and Discussion

Moisture Content and Specific Gravity

The green lodgepole pine had the highest moisture content in both the heartwood and sapwood. Average percentage moisture content of the green tree heartwood was 2 to 3 times the moisture content of the dead down and standing tree heartwood, and the green tree sapwood was 9 to 10 times the average percentage moisture content of the dead tree sapwood (table 1). The average specific gravity of the dead lodgepole pine was nearly identical to the green sample. The average specific gravity of the heartwood was greater than the sapwood average specific gravity in all three sample types, probably due to the greater extractive content in the heartwood.

Table 1.--*The average*[1] *percent moisture content and specific gravity of lodgepole and western white pine samples from green, dead down, and dead standing trees used for chemical analysis*

Analyses	Heartwood Green	Heartwood Dead down	Heartwood Dead standing	Sapwood Green	Sapwood Dead down	Sapwood Dead standing
			LODGEPOLE PINE			
Moisture content (%)	34.5 (7)	19.5 (7)	11.9 (5)	162.5 (5)	14.6 (8)	18.3 (5)
Specific gravity[2]	0.379 (20)	0.361 (10)	0.381 (12)	0.355 (15)	0.357 (14)	0.367 (9)
			WESTERN WHITE PINE			
Moisture content (%)	28.0 (2)	34.7 (2)	16.5 (2)	27.2 (2)	33.8 (2)	14.4 (2)
Specific gravity[2]	0.429 (2)	0.384 (2)	0.391 (2)	0.455 (2)	0.352 (2)	0.336 (2)

[1]The number of specimens used is indicated in parentheses.
[2]The specific gravity determinations were based on green volume and ovendry weight.

For western white pine the average percentage moisture contents of the dead down and green samples were nearly identical and about twice as high as the average percent moisture content of the dead standing sample material. The average specific gravity of the green white pine was greater than the average specific gravity of the dead down and dead standing sample material from both heartwood and sapwood. And, with the exception of the green heartwood, the average specific gravity of the heartwood was greater than the average specific gravity of the sapwood for the three wood types.

The absence of any large differences in the average specific gravity between the live and dead samples for both lodgepole and white pine suggests that the woods are physically similar.

Extractive Content

Wood extractives affect the manufacture of pulp, paper, paint, varnish, and adhesives. Also certain amounts of some components enable the living tree to resist disease. The extractives contribute to many of the properties of wood in spite of their usually limited weight.

The extractives can be classified on the basis of their solubility in a specfic solvent; however, the solubility of the extractives in different solvents may overlap (Browning 1967). The total amount of extractives in these experiments was not additive because the extractions were not carried out consecutively on the same sample. The solvents used for analysis were ether, benzene-alcohol (2:1 by volume), hot water, and 1 percent solution of sodium hydroxide. Ether is best for the saponifiables and benzene-alcohol is the best solvent for the resin acids. Materials in wood that can be extracted with hot water and a solution of sodium hydroxide include inorganic salts, sugars, cycloses, coloring matters, gums, and some phenolic substances. Chemical analysis of the various solvent extractives was not a part of the study.

The results of the extractive determinations are shown in table 2. For lodgepole pine the ether and benzene-alcohol solvents removed a greater percentage of extractives from the green wood than from the dead tree wood. The hot water and sodium hydroxide solvents, with one exception, removed greater percentages of extractive material from the dead tree wood than from the green wood. There was no consistent difference between the heartwood and sapwood for the solvents used. In general, the heartwood tended to have greater extractive content for the ether, benzene-alcohol, and hot water solvents. However, the sapwood has a greater percentage of extractive soluble in sodium hydroxide.

Table 2.--*The percentage of extractive content*[1] *of green, dead down, and dead standing lodgepole and western white pine based on the ovendry weight of wood*

Solvent	Lodgepole pine: Heartwood: Green	Lodgepole pine: Heartwood: Dead down	Lodgepole pine: Heartwood: Dead stand	Lodgepole pine: Sapwood: Green	Lodgepole pine: Sapwood: Dead down	Lodgepole pine: Sapwood: Dead stand	Western white pine: Heartwood: Green	Western white pine: Heartwood: Dead down	Western white pine: Heartwood: Dead stand	Western white pine: Sapwood: Green	Western white pine: Sapwood: Dead down	Western white pine: Sapwood: Dead stand
Ether	0.91	--	0.27	0.31	--	0.23	1.89	2.83	0.95	0.53	0.75	0.59
Benzene:alcohol (2:1 by vol.)	2.13	1.41	1.94	2.32	1.07	0.97	5.05	5.09	3.64	2.19	1.85	1.74
Hot water	3.04	3.21	5.53	2.37	2.36	3.79	4.24	4.85	1.83	2.27	3.17	2.68
1% NaOH	11.12	11.99	16.07	11.31	12.77	16.37	12.98	13.15	12.34	8.64	12.84	11.32

[1]The values are the averages of at least two determinations.

For western white pine the ether and benzene-alcohol again tended to remove greater percentages of extractive material from the green wood. No consistent trend was evident in the percentage of extractives removed by the hot water or sodium hydroxide solvents. The heartwood consistently had a greater percentage of extractive content than the sapwood, for all solvents used.

The white pine tended to have a greater amount of soluble extractive material than the lodgepole pine, perhaps because the white pine had not been dead for as long a time as the lodgepole pine.

Theoretically, holocellulose and lignin constitute the total volume of wood on the extractive-free basis. Holocellulose, the fibrous carbohydrate fraction, includes alpha-cellulose, which ideally yields only D-glucose on hydroysis, and hemicellulose, which contains xylans and glucomannans. Holocellulose constitutes the matrix of the cell wall and contributes to the elasticity and plasticity of the cell wall.

Lignin is present in the fine spaces within the cell wall where it acts as a bulking agent and reduces the dimensional changes in the cell wall. The rigidity of the lignin helps increase the cell wall stiffness.

For lodgepole pine the percentage differences between the green and dead wood samples were small, as were the percentage differences between heartwood and sapwood. The green wood of white pine had slightly higher percentages of holo- and alpha-cellulose. In all white pine samples, the sapwood had a higher alpha-cellulose and lower hemicellulose and lignin content than the heartwood (table 3).

The higher heating value of wood is primarily determined by its density and moisture content. Lignin content and, to a greater extent, the presence of extractives such as resins and tannins also affect the heating value. For the cell wall components, lignin is relatively heat stable (decomposes at 662° - 752°F (350° - 400°C)) followed by alpha-cellulose (392° - 572°F (200°-300°C)). Hemicellulose undergoes thermal decomposition at relatively lower temperatures.

Table 3--*Average percentage*[1] *of cell wall components of green, dead down, and dead standing lodgepole and western white pine based on extractive-free ovendry weight of wood*

Component	Lodgepole Heartwood Green	Lodgepole Heartwood Dead down	Lodgepole Heartwood Dead stand	Lodgepole Sapwood Green	Lodgepole Sapwood Dead down	Lodgepole Sapwood Dead stand	Western white pine Heartwood Green	Western white pine Heartwood Dead down	Western white pine Heartwood Dead stand	Western white pine Sapwood Green	Western white pine Sapwood Dead down	Western white pine Sapwood Dead stand
Holocellulose	75.45	76.06	74.64	77.18	75.11	77.23	75.60	73.62	73.63	76.12	72.92	75.40
Alpha-cellulose	43.31	44.39	42.83	43.87	45.63	45.12	40.26	38.75	39.60	45.36	40.41	44.60
Hemicellulose	32.14	31.67	31.81	33.31	29.48	32.11	35.34	34.87	34.03	30.76	32.51	30.80
Klason lignin	27.14	26.60	27.99	26.85	27.49	26.75	28.04	28.73	27.88	25.75	26.81	25.84

[1]Each value is the average of at least two determinations.

The combustion characteristics of the lodgepole and white pine wood types are shown in table 4. In general, differences between wood types, heartwood and sapwood, and between species were small and inconsistent. The heartwood of both species did have a slightly higher heat content than the sapwood. This was probably due to the heartwood's higher resin content. Also, for the lodgepole pine the dead tree samples had a higher percent ash content. Windblown dust and soil were probably the responsible factors.

Table 4.--*The combustion characteristics*[1] *of ovendry samples of green, dead down, and dead standing lodgepole and western white pine*

Characteristic	Lodgepole pine Heartwood Green	Lodgepole pine Heartwood Dead down	Lodgepole pine Heartwood Dead stand	Lodgepole pine Sapwood Green	Lodgepole pine Sapwood Dead down	Lodgepole pine Sapwood Dead stand	Western white pine Heartwood Green	Western white pine Heartwood Dead down	Western white pine Heartwood Dead stand	Western white pine Sapwood Green	Western white pine Sapwood Dead down	Western white pine Sapwood Dead stand
Higher heating value mJ/kg[2]	19.98	19.87	20.11	19.90	19.49	19.60	20.31	20.44	20.18	19.79	19.78	19.47
Yield of char[3] %	30.04	29.18	29.55	29.60	29.48	28.10	28.93	28.44	28.47	28.14	27.94	27.00
Higher heating value of char mJ/kg	29.77	30.14	30.23	30.28	30.15	30.31	31.17	30.99	31.17	31.27	31.12	31.07
Ash[3] %	0.34	0.43	0.55	0.36	0.51	0.53	0.36	0.28	0.30	0.29	0.29	0.23

[1]Each value is the average of at least two determinations.
[2]Megajoules per kilogram.
[3]Based on ovendry weight of wood.

The results of the chemical and physical determinations for green and dead wood of the two study species are summarized in table 5. This table also contains a listing of values, obtained from the literature, for the extractive contents and cell wall components. The table emphasizes the differences pointed out earlier and also indicates that the study data are, in general, comparable to published data. Differences can, perhaps, be attributed to the age, size, and location from which the different samples were taken.

Table 5.--*Summary of the chemical and physical characteristics of live and dead wood from lodgepole and western white pine*

Characteristics	Lodgepole pine			Western white pine		
	Lit.[1]	Green	Dead	Lit.[2]	Green	Dead
Specific gravity	--	0.367	0.367	--	0.442	0.366
Extractives[3]						
Ether	1.3	0.61	0.25	5.6	1.21	1.28
Benzene:alcohol (2:1 by vol.)	2.8	2.23	1.35	8.3	3.62	3.08
Hot water	3.7	2.71	3.72	3.7	3.26	3.88
1% NaOH	11.6	11.22	14.30	15.6	10.81	12.49
Cell wall component[3]						
Holocellulose	71.6	76.31	75.76	64.3	75.86	73.89
Alpha-cellulose	47.3	43.59	44.49	42.3	42.81	40.84
Hemicellulose	24.3	32.72	31.27	22.0	33.05	33.05
Klason lignin	25.9	26.70	27.21	25.4	26.90	27.32
Combustion						
Heating value[4]	--	19.95	19.77	--	20.05	19.96
Yield of char %	--	29.82	29.08	--	28.54	27.96
Heating value of char[4]	--	30.02	30.21	--	31.22	30.09
Ash %	0.2	0.35	0.51	0.3	0.33	0.28

[1]Data from: McGovern, J. N. 1951. (Pulping of lodgepole pine, USDA Forest Service FPL R1792, Madison, Wis.)

[2]Data from: Isenberg, I. H. 1951. (Pulpwoods of United States and Canada. Second Edition. The Inst. of Paper Chemistry, Appleton, Wis.)

[3]Values shown are percentages.

[4]mJ/kg (Megajoules per kilogram).

CONCLUSIONS

Tests of heartwood and sapwood from green, dead down, and dead standing lodgepole and western white pine indicated that the wood is chemically and physically similiar. Specific gravity was nearly the same for both green wood and dead wood, indicating no decay of the sample material. The sample from dead trees had a lower moisture content (percentage) than samples from the green trees. The extractive content for the green wood was slightly higher than for the dead wood. Percentages of cell wall components were essentially the same for the three wood types and the effect of species was small. Also, combustion characteristics were similiar. The study results, based on single trees of each type, indicate that wood from dead trees is comparable to wood from green trees. As a result, dead trees should be considered a source of chemicals, fuel, and new material for board, pulp, and paper.

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