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TURN CYCLE TIME PREDICTION FOR RUBBER TIRED SKIDDERS IN THE NORTHERN ROCKIES

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ABSTRACT

A study of rubber tired skidders shows cycle turn times are best predicted by categorizing the skidders as small or large and basing the classification on weight and horsepower. Regression equations show that turn times for heavier skidders can be predicted with better accuracy than can turn times for the light weight skidders.

KEYWORDS: rubber tired skidders, cycle turn time

In the past decade articulated rubber tired skidders have largely replaced tracked vehicles for ground skidding, especially for less than 35 percent slopes. The skidders have two principal advantages over tracked vehicles--speed and maneuverability. For most tracked vehicle/skidder models of comparable size, skidders are usually less expensive because of the lower cost of the undercarriage.

Over two logging seasons 10 different skidder models of seven different manufacturers were studied. The studies included a total of 579 skidding turns.

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EQUIPMENT AND CLASSIFICATION

All of the skidders studied were articulated with an integral arch and chokers. A summary of the skidders by size class and other characteristics is given in table 1. For analysis three classifications were assumed, small, large, and all skidders. The smaller skidders generally weighed from 10,000 to 12,000 pounds (4,536 to 5,443 kg), and had about 75 horsepower and a synchromesh transmission. The larger machines had powershift tranmissions, weighed from 15,000 to 18,500 pounds (6,804 to 8,392 kg), and averaged about 130 horsepower. The large skidders were capable of the greatest speed.

Table 1.--*Equipment classification and characteristics*

Characteristics								
Classification	Make (model)	Transmission	Horsepower	Weight pounds (kilogram)	Wheelbase feet (meters)	Tire width inches (meters)	Maximum travel speed miles per hour (kilometers)	Clearance feet (meters)
Small	John Deere (440 A)	synchro	70	11,920 (5,192)	7.4 (2.3)	14.9 (.38)	16.0 (25.7)	1.5 (.46)
	John Deere (440 B)	synchro	70	12,250 (5,336)	7.4 (2.3)	16.9 (.43)	17.5 (28.2)	1.5 (.46)
	Pettibone (Master 8)	synchro (standard)	79	11,150 (4,857)	7.5 (2.3)	12.0 (.30)	15.5 (24.9)	1.5 (.46)
	International (S-7 B)	synchro	85	10,500 (4,574)	7.7 (2.3)	16.9 (.43)	16.0 (25.7)	2.0 (.61)
Large	Clark (667)	powershift	109	18,520 (8,067)	9.1 (2.8)	18.4 (.47)	18.0 (29.0)	1.7 (.52)
	Caterpillar (518)	powershift	120	17,300 (7,536)	9.4 (2.9)	18.4 (.47)	17.0 (27.4)	1.4 (.43)
	Clark (666)	powershift	128	14,900 (6,490)	8.7 (2.6)	18.4 (.47)	28.4 (45.7)	1.7 (.52)
	Timberjack (404)	powershift	130	16,000 (6,970)	9.6 (2.9)	18.4 (.47)	18.0 (29.0)	1.9 (.58)
	Garrett (22)	powershift	135	15,400 (6,708)	9.0 (2.7)	18.4 (.47)	19.4 (31.2)	1.9 (.58)
	International (S-11)	powershift	150	18,500 (8,059)	9.6 (2.9)	18.4 (.47)	23.3 (37.5)	2.1 (.64)

ANALYSIS AND PREDICTION EQUATIONS

A stepwise regression analysis was performed on the data. The variables of distance, volume, number of logs, weight, slope and various transformations totaling 44 variables were used. The transformations did not appreciably improve the correlation coefficients so the final equations contain some combination of the following principal variables:

NL = Number of logs

VOL = Volume in board feet (m^3)

WT = Weight of turn in pounds (kg)

DITOT = Total skidding distance in feet (m)

TT = Turn time in minutes

Equations for Turn Time

Large tractors:

$$TT = -0.1971 + 1.1287\ NL + 0.0045\ VOL + 0.0063\ DITOT \qquad (1)$$
$$R^2 = 0.8421$$

Small tractors:

$$TT = 6.58 - 0.368\ NL + 0.00065\ WT + 0.0168\ DITOT \qquad (2)$$
$$R^2 = 0.5483$$

All tractors:

$$TT = 2.57 + 0.8228\ NL + 0.0054\ VOL + 0.0078\ DITOT \qquad (3)$$
$$R^2 = 0.7550$$

Data on the variables are summarized in table 2.

Table 2.--*Summary of all data*

	Maximum	Minimum	Mean
Board ft per hour	12,000	45	2,274
(m^3)	(54)	(0.20)	(10.3)
Total turn time (minutes)	35.5	2.0	12.96
Number of logs	16.0	1.0	5.56
Volume per turn (board feet)	3,610	15	486
(m^3)	(16.3)	(0.07)	(2.2)
Weight (pounds)	25,326	220	3.691
(kg)	(11,498)	(100)	(1,676)
Total distance (feet)	4,100	100	1,029
(m)	(1,250)	(30.5)	(314)
Slope percent	15	-50	11

Equations (1) and (2) should be used if the skidder falls into the large or small skidder weight and horsepower classification. If an estimate of average turn times for a group of tractors of different sizes is desired use equation (3).

To facilitate solving the above equations for turn times use the nomographs shown in figures 1, 2, and 3. Each nomograph contains an example problem. The dotted lines in the figures illustrate how to use the graphs. To solve for other combinations of variables use any two straight-edged materials, preferably clear plastic, to locate the index point on the nondimensioned scale. Connect the index point with the appropriate point on the total distance scale. The intersection of this line with the TT scale gives the turn time in minutes for the selected variables.

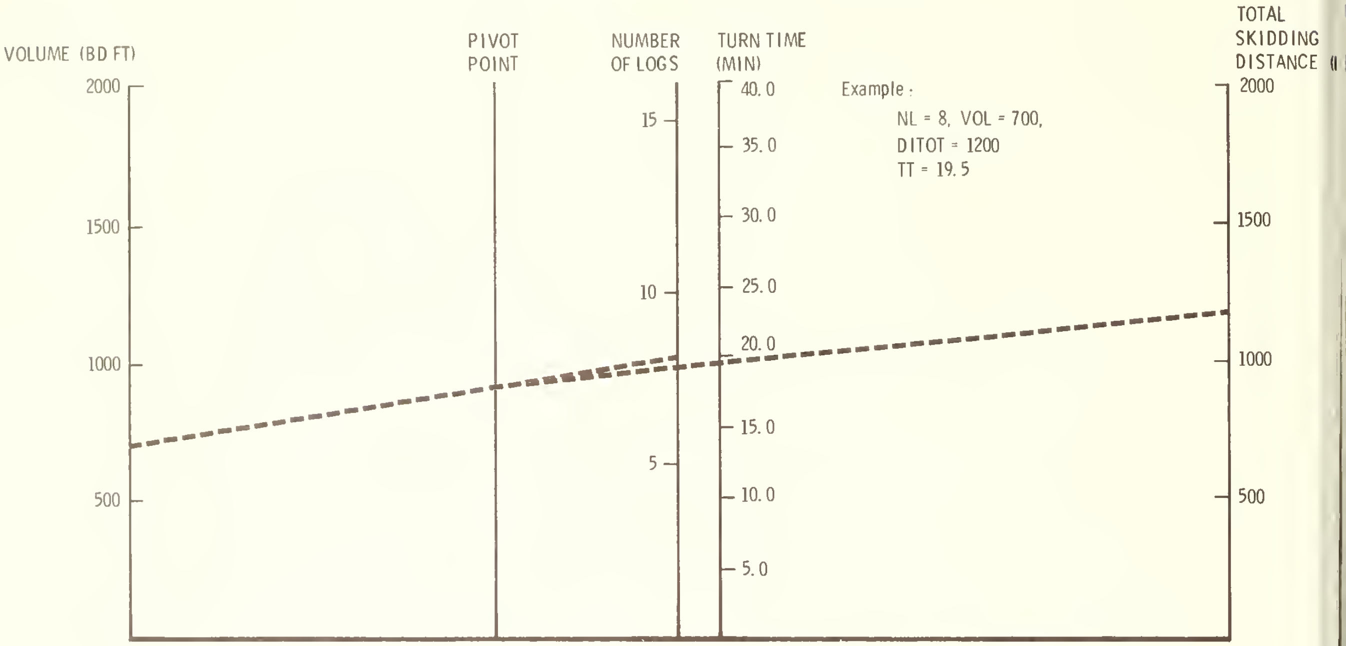

Figure 1.--*Large skidders*

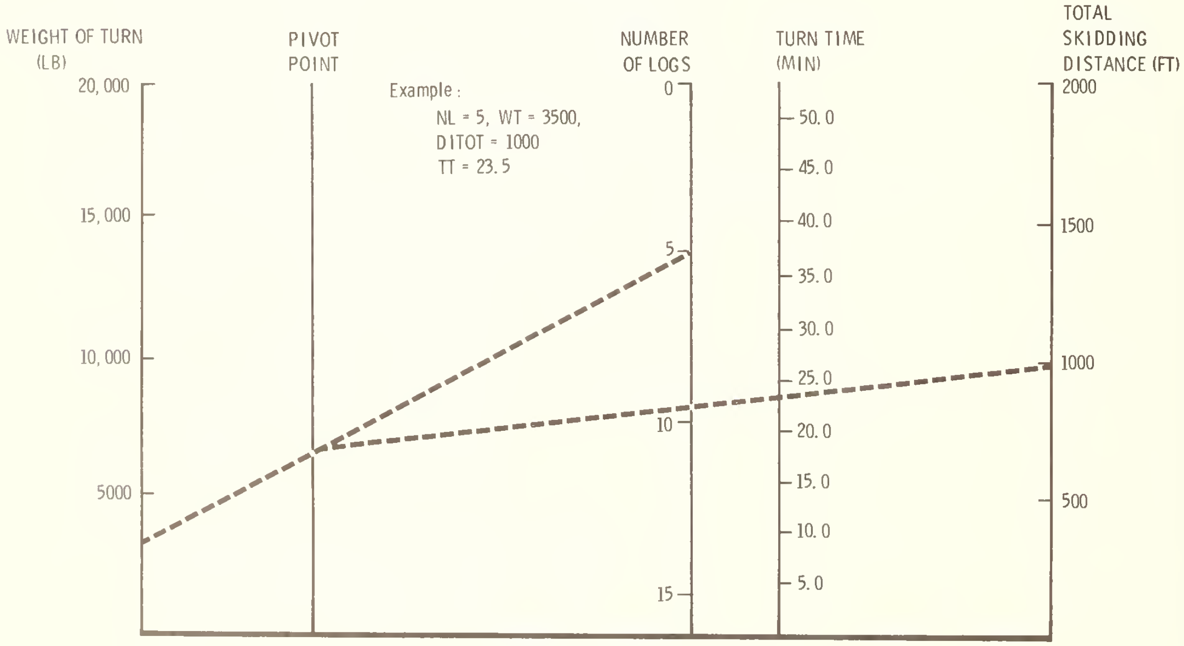

Figure 2.--*Small skidders*

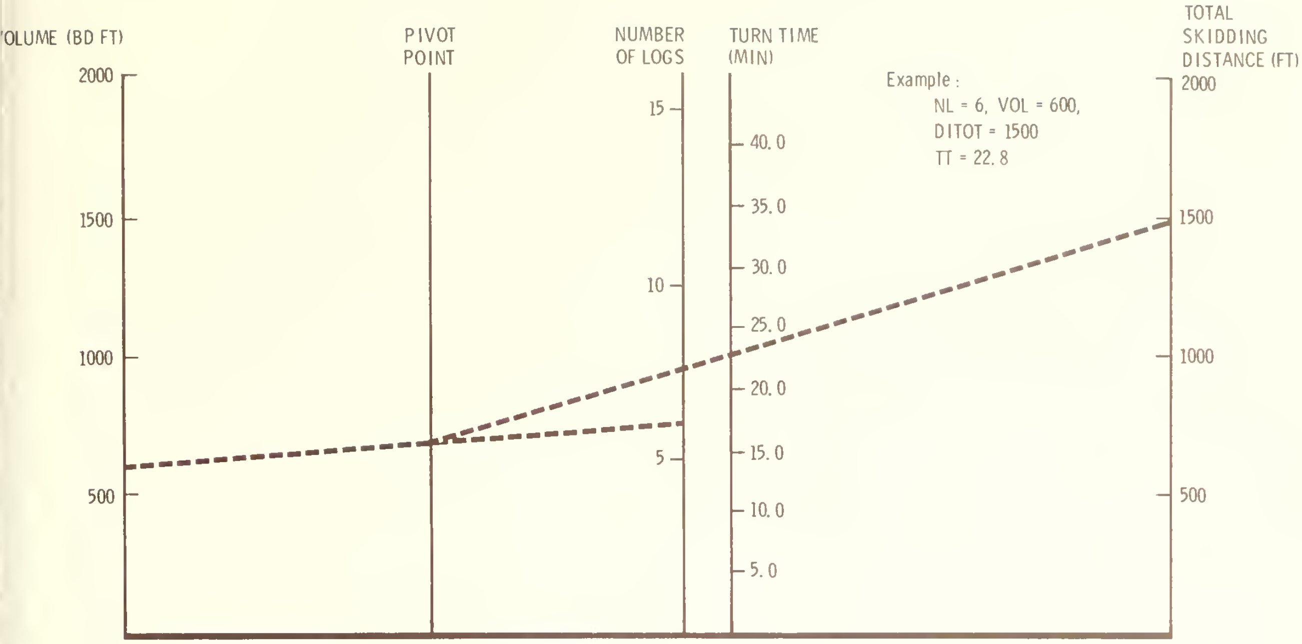

Figure 3.--*All skidders*

CONCLUSIONS

Turn cycle times for rubber tired skidders can be computed by using equations containing the three principal variables. The skidders were divided into two size classes by weight and horsepower to obtain better estimating equations. Also, an equation for all tractors is included. In this study better results were obtained for the heavier skidders whose turn times proved to be less variable.

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FOREST AREA AND TIMBER RESOURCE STATISTICS FOR THE BOZEMAN WORKING CIRCLE, MONTANA, 1976

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ABSTRACT

Presents land area, commercial timberland area, timber inventory, and growth and mortality data based on Renewable Resources Evaluation standards.

KEYWORDS: forest surveys (regional), forest area classification, stand volume.

INTRODUCTION

A comprehensive timber resource study was conducted on State and private lands in the Bozeman Working Circle, Montana, in 1976, by the Montana Department of Natural Resources and Conservation, Division of Forestry, in cooperation with the Forest Service, Region 1, Division of State and Private Forestry, and the Intermountain Forest and Range Experiment Station.

The Bozeman Working Circle includes Gallatin, Meagher, and Park Counties (see fig. 1). The total land area is 5.0 million acres (2.0 million hectares). The Forest Service, the Bureau of Land Management, and miscellaneous Federal owners administer 2.1 million acres (0.8 million hectares) of this land. The remainder is in State and private ownership. This note presents data from State and private lands only.

Highlights show the area of commercial timberland in comparison to total forest land area, and the distribution of this area by forest type, stand-size class, and site class. Discussions of the data reliability and terminology are included. These two items should be reviewed carefully when using this information.

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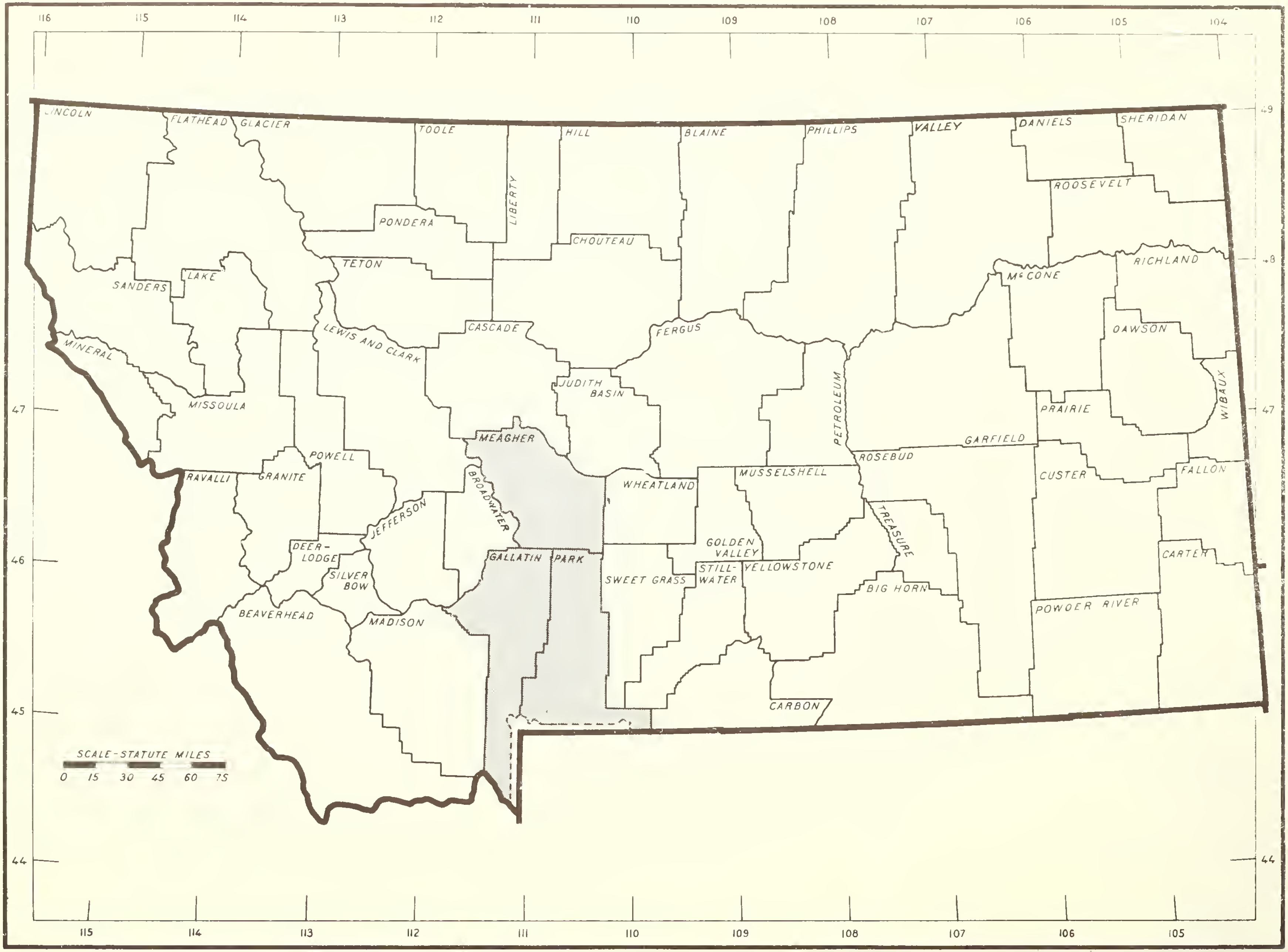
[1] Respectively, Supervisory Statistical Assistant and Statistical Assistant.

MONTANA


LINCOLN
FLATHEAD
GLACIER
TOOLE
LIBERTY
HILL
BLAINE
PHILLIPS
VALLEY
DANIELS
SHERIDAN
ROOSEVELT
PONDERA
CHOUTEAU
TETON
RICHLAND
McCONE
SANDERS
LAKE
CASCADE
FERGUS
LEWIS AND CLARK
DAWSON
MINERAL
JUDITH BASIN
MISSOULA
PETROLEUM
WIBAUX
PRAIRIE
MEAGHER
GARFIELD
POWELL
ROSEBUD
RAVALLI
GRANITE
MUSSELSHELL
CUSTER
FALLON
WHEATLAND
BROADWATER
JEFFERSON
TREASURE
DEER-LODGE
GOLDEN VALLEY
CARTER
GALLATIN
PARK
SILVER BOW
STILL-WATER
YELLOWSTONE
SWEET GRASS
BIG HORN
BEAVERHEAD
MADISON
POWDER RIVER
CARBON
SCALE-STATUTE MILES
0 15 30 45 60 75
116 115 114 113 112 111 110 109 108 107 106 105 104
49 48 47 46 45 44

HIGHLIGHTS

AREA

- The forest land area is 657 thousand acres (266 thousand hectares), or 22 percent of the total State and private land area in the Working Circle.

- Of the forest land, 586 thousand acres (237 thousand hectares), or 89 percent, is classified as commercial timberland.

- Private ownership accounts for 559 thousand acres (226 thousand hectares), or 95 percent, of the commercial timberland.

- The predominant forest types are Douglas-fir, lodgepole pine, and spruce-subalpine fir; they occupy 87 percent of the commercial timberland. The remaining area consists of whitebark-limber pine, ponderosa pine, juniper,[2] and hardwood forest types.

- Almost 70 percent of the commercial timberland supports sawtimber stands; poletimber stands make up 19 percent. The remainder is in sapling and seedling stands or nonstocked.

- Nearly 83 percent of the commercial timberland is in the 20 to 49 cubic-foot productivity class, 95 percent of which is privately owned.

INVENTORY

- Growing stock volume amounts to 930 million cubic feet (26 million cubic meters) with the major portion, about 67 percent, in softwood sawtimber trees.

- Rough, rotten, and salvable dead trees comprise 103 million cubic feet (3 million cubic meters), or 10 percent, of the total sound wood volume.

- About 92 percent of the 3,097 million board feet[3] of sawtimber volume is in sawtimber trees less than 23.0 inches d.b.h.

- Douglas-fir (47.6 percent) and lodgepole pine (26.6 percent) make up 74.2 percent of the growing stock volume and 73.9 percent of the sawtimber volume. Species sharing the remaining percentage are Engelmann spruce, whitebark-limber pine, subalpine fir, ponderosa pine, juniper, aspen and other hardwoods.

- Private owners control 95 percent of the softwood growing stock volume and 95 percent of the softwood sawtimber volume.

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[2] The area occupied by juniper forest type classified as commercial is so classified because the site index for other associated species on these stands (usually ponderosa pine or Douglas-fir) is high enough to indicate a potential productivity level exceeding 20 cubic feet per acre per year average annual growth, and nonstockable indicators are not present in sufficient quantities to lower the yield capability below 20 cubic feet per acre per year. Although juniper usually occurs on unproductive forest land, when it occurs in mixtures with other species on productive sites, it is reported in the commercial timberland statistics.

[3] International 1/4-inch rule.

GROWTH AND MORTALITY

- Net annual growth of growing stock totals 12,171 thousand cubic feet (345 thousand cubic meters) with 95 percent occurring in softwood species, mainly Douglas-fir, lodgepole pine, and subalpine fir. Growth and mortality were not measured for juniper trees.
- About 95 percent of the total net growth is on private lands.
- The annual mortality of 5,682 thousand cubic feet (161 thousand cubic meters) offsets 32 percent of the gross annual growth.
- Weather and unknown factors account for 75 percent of the mortality. The remainder was caused by suppression, insects, disease, and fire.
- Seventy-three percent of the mortality occurs in the lodgepole pine and Douglas-fir species.

DATA RELIABILITY

The sampling errors presented in tables 1 and 2 are in terms of one standard error--the 67 percent confidence level. Individual cells within tables should be used with caution. Some are based on small sample sizes, thus resulting in high sampling errors.

Table 1.--*Forest land area and associated sampling error percentages for the Bozeman Working Circle, 1976*

Item	Softwood types		Hardwood types		All types	
	Acres	Percent	Acres	Percent	Acres	Percent
Commercial timberland	557,242	2.7	29,055	27.3	586,297	2.6
Other forest land:						
Unproductive reserved	--	--	--	--	--	--
Unproductive nonreserved	44,823	24.5	26,156	34.3	70,979	19.2

Table 2.--*Net Volume, net annual growth and annual mortality on commercial timberland, with associated sampling error percentages for the Bozeman Working Circle, 1976*

Item	Softwoods		Hardwoods		All species	
	Volume	Percent	Volume	Percent	Volume	Percent
Volume:						
Growing stock (M cubic feet)	905,198	5.0	24,992	26.6	930,190	4.9
Sawtimber (M board feet[1])	3,056,184	6.0	40,464	31.5	3,096,648	6.0
Net Growth:						
Growing stock (cubic feet)	11,610,357	11.2	560,367	50.4	12,170,724	10.9
Sawtimber (board feet[1])	62,080,920	12.9	1,632,272	84.8	63,713,192	12.7
Mortality:						
Growing stock (cubic feet)	5,281,460	17.1	400,811	37.4	5,682,271	16.2
Sawtimber (board feet[1])	17,507,218	21.7	696,414	72.5	18,203,632	21.2

[1] International 1/4-inch rule.

TERMINOLOGY AND DATA TABLES

The following section contains definitions, taken directly from the Forest Service Forest Survey Handbook, that are relevant to the timber resource data presented in this Research Note. Forest area and timber resource data for the Bozeman Working Circle, Montana, are displayed in tables 3 through 23.

TERMINOLOGY

Land Use Classes

LAND AREA

Bureau of the Census.--The area of dry land and land temporarily or partly covered by water, such as marshes, swamps, and river flood plains; streams, sloughs, estuaries, and canals less than 1/8 of a statute mile in width; and lakes, reservoirs, and ponds less than 40 acres in area.

WATER

Census water.--As defined by the Bureau of Census, streams, sloughs, estuaries, and canals more than 1/8 of a statute mile in width; and lakes, reservoirs, and ponds more than 40 acres in area.

Noncensus water.--The same as defined by the Bureau of the Census, except minimum width of streams, etc., is 120 feet and minimum size of lakes, etc., is 1 acre.

Forest land.--Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use.

Commercial timberland.--Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying have the capability of producing in excess of 20 cubic feet per acre per year of industrial wood under management. Currently inaccessible and inoperable areas are included, except when the areas involved are small and unlikely to become suitable for production of industrial wood in the foreseeable future.)

Productive-reserved forest land.--Forest land sufficiently productive to qualify as commercial timberland, but withdrawn from timber utilization through statute, administrative designation, or exclusive use for Christmas tree production.

Other forest land.--(1) Forest land incapable of producing 20 cubic feet per acre of industrial wood under management, because of adverse site conditions; (2) unproductive-reserved forest land.

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

Ownership Classes

National Forest land.--Federal lands that 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.

Bureau of Land Management lands.--Federal land administered by the Bureau of Land Management.

Indian lands.--Tribal lands held in fee by the Federal Government, but administere for Indian tribal groups and Indian trust allotments.

State.--Lands owned by States, or lands leased to these governmental units for 50 years or more.

PRIVATE AND OTHER

County and municipal lands.--Lands owned by counties and local public agencies or municipalities, or lands leased to these governmental units for 50 years or more.

Forest industry lands.--Lands owned by companies or individuals operating wood-usi plants.

Farmer-owned lands.--Lands owned by farm operators. (Note: These exclude lands leased by farm operators from nonfarm owners, such as railroad companies and States.)

Miscellaneous Federal lands.--Federal lands other than the following: (1) National Forest lands; (2) lands administered by the Bureau of Land Management; and (3) Indian lands.

Miscellaneous private lands.--Privately owned lands other than forest industry and farmer-owned lands.

Forest Type and Tree Species

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

Forest trees.--Woody plants having a well-developed stem and usually more than 12 feet in height at maturity.

Commercial species.--Tree species presently or prospectively suitable for industri wood products.

Softwoods.--Coniferous trees, usually evergreen, having needles or scalelike leave

Hardwoods.--Dicotyledonous trees, usually broad-leaved and deciduous.

Area Condition Classes

Stocking.--Stocking is an effort to express the extent to which growing space is effectively utilized by present or potential growing stock trees or commercial species. "Percent of stocking" is synonymous with "percentage of growing space occupied" and means the ratio of actual stocking to full stocking for comparable sites and stands. Basal area is used as a basis for measuring stocking.

"Stocking percentages" express current area occupancy in relation to specified standards for full stocking based on number, size, and spacing of trees considered necessary to fully utilize the forest land.

Full utilization of the site occurs over a range of basal area. Sixty percent of the normal yield table values has been used to establish the lower limit of this range, which represents full-site occupancy. This is called 100-percent stocking. The upper limit of full stocking has been set at 132 percent. Sites with less than 100-percent stocking represent understocking. Overstocking is characterized by sites with over 133 percent stocking.

Class 10.--Area fully stocked (100-132 percent) with desirable trees and not overstocked (133 percent or more).

Class 20.--Area fully stocked with desirable trees, but overstocked with all live trees.

Class 30.--Areas medium to fully stocked (60-99 percent) with desirable trees and with less than 30 percent of the area controlled by other trees and (or) inhibiting vegetation or surface conditions that will prevent occupancy by desirable trees.

Class 40.--Areas medium to fully stocked with desirable trees and with 30 percent or more of the area controlled by other trees and (or) conditions that ordinarily prevent occupancy by desirable trees.

Class 50.--Areas poorly stocked (16.7-59 percent) with desirable trees, but fully stocked with growing stock trees.

Class 60.--Areas poorly stocked with desirable trees, but with medium to full stocking of growing stock trees.

Class 70.--Areas nonstocked (less than 16.7 percent) or poorly stocked with desirable trees, and poorly stocked with growing stock trees.

Class 80.--Low-risk old-growth stands.

Class 90.--High-risk old-growth stands.

Nonstocked.--Areas less than 16.7 percent stocked with growing stock trees.

Class of Timber

Growing stock trees.--Live trees of commercial species qualifying as desirable or acceptable trees. (Note: Excludes rough, rotten, and dead trees.)

Desirable trees.--Growing stock trees (a) having no serious defect in quality limiting present or prospective use for timber products; (b) of relatively high vigor; and (c) containing no pathogens that may result in death or serious deterioration before rotation age.

Acceptable trees.--Growing stock trees that meet specified standards of size and quality, but not qualifying as desirable trees.

Rough trees.--(1) Live trees of commercial species that do not contain at least one 12-foot saw log or two noncontiguous saw logs, each 8 feet long or longer, now or prospectively, and (or) do not meet Regional specifications for freedom from defect primarily because of roughness or poor form; (2) all live trees of noncommercial species.

Rotten trees.--Live trees that do not contain at least one 12-foot saw log or two noncontiguous saw logs, each 8 feet long or longer, now or prospectively, and (or) do not meet Regional specifications for freedom from defect primarily because of rot; that is, when more than 50 percent of the cull volume (cubic-foot basis) in a tree is rotten.

Cull.--Portions of a tree that are unusable for industrial wood products because of rot, form, or other defect.

Salvable dead trees.--Standing or down dead trees that are considered merchantable by Regional standards.

Mortality trees.--Trees, formerly growing stock, dying from natural causes during a a specified period, usually 1 year.

Saw-log portion.--That part of the bole of sawtimber trees between the stump and the saw log top. A 1-foot stump is used.

Upper-stem portion.--That part of the bole of sawtimber trees above the saw log top to a minimum top diameter of 4.0 inches outside bark or to the point where the central stem breaks into limbs, whichever occurs first.

Tree Size Classes

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

Saplings.--Trees 1.0-4.9 inches in diameter at breast height.

Poletimber trees.--Trees at least 5.0 inches in d.b.h., but smaller than sawtimber size.

Sawtimber trees.--Trees exceeding poletimber size. In the Intermountain States, the minimum d.b.h. for softwood sawtimber is 9.0 inches, and 11.0 inches for hardwoods.

Volume

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

Growing stock volume.--Net volume in cubic feet of live sawtimber trees and live poletimber trees from stump to a minimum 4.0-inch top (of central stem) outside bark. Net volume equals gross volume less deduction for rot and missing bole sections.

Sawtimber volume.--Net volume in board feet of sawtimber trees of commercial speci Net volume equals gross volume less deduction for rot, sweep, crook, and other defects that affect use for lumber.

Growth and Mortality

Net annual growth.--The increase in net growing stock volume of a specified size class for a specific year. (Note: Components of net annual growth include the incremen 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.)

Mortality.--Number or sound-wood volume of growing stock trees dying from natural causes during a specified period.

Site

Site class.--A classification of forest land in terms of inherent capacity to grow crops of industrial wood.

Site classifications are based upon the mean net annual growth of growing stock (not including thinnings or mortality loss) attainable at culmination of mean net annua growth over age. Height-age relationships are usually used as indicators of the specified volume-site class.

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 of this stocking 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 of the stocking is saplings and (or) seedlings.

Nonstocked land.--Commercial timberland less than 16.7 percent stocked with growing stock trees.

Table 3.--*Total area in the Bozeman Working Circle by ownership class, 1976*

Ownership class	Acres	Hectares
National Forest	1,840,447	744,806
Bureau of Land Management	38,777	15,693
National Park Service[1]	167,710	67,870
State	202,807	82,073
Private and other	2,720,499	1,100,951
Total land area	4,970,240	2,011,393
Census water	19,200	7,770
Gross area[2]	4,989,440	2,019,163

[1] Not included with Miscellaneous Federal (a category of private and other) for purposes of clarity.

[2] U.S. Bureau of the Census, land and water area of the United States, 1970.

Table 4.--*Land area in the Bozeman Working Circle by major land class and ownership class, 1976*

Land class	Ownership class			
	State		Private[1]	
	Acres	Hectares	Acres	Hectares
Commercial timberland	27,091	10,963	559,206	226,304
Productive reserved	--	--	--	--
Other forest land:				
Unproductive reserved	--	--	--	--
Unproductive nonreserved	3,826	1,548	67,153	27,176
Total forest land	30,917	12,511	626,359	253,480
Nonforest land	171,890	69,562	2,094,140	847,471
Total land area	202,807	82,073	2,720,499	1,100,951

[1] On this and all later tables, the private ownership category includes a small portion of County and municipal ownership.

Table 5.--*Area of commercial timberland in the Bozeman Working Circle by forest type, stand-size class, and site class, State owned, 1976*

Forest type and stand-size class	Site class 165+	120-164	85-119	50-84	20-49	Total acres
	Acres					
Douglas-fir:						
Sawtimber	--	--	--	2,603	9,297	11,900
Poletimber	--	--	--	--	2,421	2,421
Sapling and seedling	--	--	--	--	268	268
Nonstocked	--	--	--	--	--	--
Total	--	--	--	2,603	11,986	14,589
Ponderosa pine:						
Sawtimber	--	--	--	--	613	613
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	613	613
Lodgepole pine:						
Sawtimber	--	--	--	552	2,376	2,928
Poletimber	--	--	--	242	1,615	1,857
Sapling and seedling	--	--	--	--	195	195
Nonstocked	--	--	--	--	353	353
Total	--	--	--	794	4,539	5,333
Whitebark-limber pine:						
Sawtimber	--	--	--	190	1,001	1,191
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	163	163
Nonstocked	--	--	--	--	--	--
Total	--	--	--	190	1,164	1,354
Spruce-subalpine fir:						
Sawtimber	--	--	--	988	1,407	2,395
Poletimber	--	--	--	119	--	119
Sapling and seedling	--	--	--	--	336	336
Nonstocked	--	--	--	--	--	--
Total	--	--	--	1,107	1,743	2,850
Juniper:						
Sawtimber	--	--	--	--	48	48
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	195	195
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	243	243
Aspen:						
Sawtimber	--	--	--	--	--	--
Poletimber	--	--	--	--	780	780
Sapling and seedling	--	--	--	550	259	809
Nonstocked	--	--	--	--	--	--
Total	--	--	--	550	1,039	1,589
Cottonwood:						
Sawtimber	--	--	--	--	260	260
Poletimber	--	--	--	--	260	260
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	520	520
All types:						
Sawtimber	--	--	--	4,333	15,002	19,335
Poletimber	--	--	--	361	5,076	5,437
Sapling and seedling	--	--	--	550	1,416	1,966
Nonstocked	--	--	--	--	353	353
Total	--	--	--	5,244	21,847	27,091

Table 6.--*Area of commercial timberland in the Bozeman Working Circle by forest type, stand-size class, and site class, private owned, 1976*

Forest type and stand-size class	Site class					Total acres
	165+	120-164	85-119	50-84	20-49	
	Acres					
Douglas-fir:						
Sawtimber	--	--	--	45,699	199,712	245,411
Poletimber	--	--	--	--	54,170	54,170
Sapling and seedling	--	--	--	--	6,991	6,991
Nonstocked	--	--	--	--	3,871	3,871
Total	--	--	--	45,699	264,744	310,443
Ponderosa pine:						
Sawtimber	--	--	--	--	14,290	14,290
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	14,290	14,290
Lodgepole pine:						
Sawtimber	--	--	--	11,074	42,391	53,465
Poletimber	--	--	--	3,502	28,657	32,159
Sapling and seedling	--	--	--	--	11,472	11,472
Nonstocked	--	--	--	3,870	6,875	10,745
Total	--	--	--	18,446	89,395	107,841
Whitebark-limber pine:						
Sawtimber	--	--	--	3,373	17,436	20,809
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	3,502	3,502
Nonstocked	--	--	--	--	--	--
Total	--	--	--	3,373	20,938	24,311
Spruce-subalpine fir:						
Sawtimber	--	--	--	17,412	32,151	49,563
Poletimber	--	--	--	4,002	--	4,002
Sapling and seedling	--	--	--	--	10,869	10,869
Nonstocked	--	--	--	--	3,871	3,871
Total	--	--	--	21,414	46,891	68,305
Juniper:						
Sawtimber	--	--	--	--	3,340	3,340
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	3,730	3,730
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	7,070	7,070
Aspen:						
Sawtimber	--	--	--	--	--	--
Poletimber	--	--	--	--	9,755	9,755
Sapling and seedling	--	--	--	7,110	3,577	10,687
Nonstocked	--	--	--	--	--	--
Total	--	--	--	7,110	13,332	20,442
Cottonwood:						
Sawtimber	--	--	--	--	3,252	3,252
Poletimber	--	--	--	--	3,252	3,252
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	6,504	6,504
All types:						
Sawtimber	--	--	--	77,558	312,572	390,130
Poletimber	--	--	--	7,504	95,834	103,338
Sapling and seedling	--	--	--	7,110	40,141	47,251
Nonstocked	--	--	--	3,870	14,617	18,487
Total	--	--	--	96,042	463,164	559,206

Table 7.--*Area of commercial timberland in the Bozeman Working Circle by forest type, stand-size class, and site class, summary--State and private, 1976*

Forest type and stand-size class	Site class: 165+	120-164	85-119	50-84	20-49	Total acres
	Acres					
Douglas-fir:						
Sawtimber	--	--	--	48,302	209,009	257,311
Poletimber	--	--	--	--	56,591	56,591
Sapling and seedling	--	--	--	--	7,259	7,259
Nonstocked	--	--	--	--	3,871	3,871
Total	--	--	--	48,302	276,730	325,032
Ponderosa pine:						
Sawtimber	--	--	--	--	14,903	14,903
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	14,903	14,903
Lodgepole pine:						
Sawtimber	--	--	--	11,626	44,767	56,393
Poletimber	--	--	--	3,744	30,272	34,016
Sapling and seedling	--	--	--	--	11,667	11,667
Nonstocked	--	--	--	3,870	7,228	11,098
Total	--	--	--	19,240	93,934	113,174
Whitebark-limber pine:						
Sawtimber	--	--	--	3,563	18,437	22,000
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	3,665	3,665
Nonstocked	--	--	--	--	--	--
Total	--	--	--	3,563	22,102	25,665
Spruce-subalpine fir:						
Sawtimber	--	--	--	18,400	33,558	51,958
Poletimber	--	--	--	4,121	--	4,121
Sapling and seedling	--	--	--	--	11,205	11,205
Nonstocked	--	--	--	--	3,871	3,871
Total	--	--	--	22,521	48,634	71,155
Juniper:						
Sawtimber	--	--	--	--	3,388	3,388
Poletimber	--	--	--	--	--	--
Sapling and seedling	--	--	--	--	3,925	3,925
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	7,313	7,313
Aspen:						
Sawtimber	--	--	--	--	--	--
Poletimber	--	--	--	--	10,535	10,535
Sapling and seedling	--	--	--	7,660	3,836	11,496
Nonstocked	--	--	--	--	--	--
Total	--	--	--	7,660	14,371	22,031
Cottonwood:						
Sawtimber	--	--	--	--	3,512	3,512
Poletimber	--	--	--	--	3,512	3,512
Sapling and seedling	--	--	--	--	--	--
Nonstocked	--	--	--	--	--	--
Total	--	--	--	--	7,024	7,024
All types:						
Sawtimber	--	--	--	81,891	327,574	409,465
Poletimber	--	--	--	7,865	100,910	108,775
Sapling and seedling	--	--	--	7,660	41,557	49,217
Nonstocked	--	--	--	3,870	14,970	18,840
Total	--	--	--	101,286	485,011	586,297

Table 8.--*Area of commercial timberland in the Bozeman Working Circle by stand volume and ownership classes, 1976*

Stand volume per acre[1]	Ownership class		
	State	Private	State and private
	- - - - - - - - - - - - *Acres*	- - - - - - - - - - - -	
Less than 1,500 board feet	6,997	146,847	153,844
1,500 to 4,999 board feet	8,325	178,064	186,389
5,000 to 9,999 board feet	6,811	135,711	142,522
10,000 board feet or more	4,958	98,584	103,542
All classes	27,091	559,206	586,297

[1] International 1/4-inch rule.

Table 9.--*Area of commercial timberland in the Bozeman Working Circle by forest type and area condition class; State and private, 1976*

Forest type	Area condition class									Nonstocked	All classes	
	10	20	30	40	50	60	70	80	90			
	- - - - - - - - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	*Acres*	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- *Hectares* -
Douglas-fir	--	--	--	23,017	29,802	129,785	59,544	--	79,013	3,871	325,032	131,536
Ponderosa pine	--	--	--	--	--	--	3,875	3,744	7,284	--	14,903	6,031
Lodgepole pine	--	3,836	3,871	7,707	30,778	18,833	11,689	3,744	21,618	11,098	113,174	45,800
Whitebark-limber pine	--	--	--	--	--	3,665	7,636	--	14,364	--	25,665	10,386
Spruce-subalpine fir	--	--	3,836	3,744	7,865	14,948	3,870	10,902	22,119	3,871	71,155	28,796
Juniper	--	--	--	--	--	7,313	--	--	--	--	7,313	2,960
Total softwoods	--	3,836	7,707	34,468	68,445	174,544	86,614	18,390	144,398	18,840	557,242	225,509
Aspen	--	--	--	--	3,512	11,171	7,348	--	--	-	22,031	8,916
Cottonwood	--	--	--	--	--	3,512	3,512	--	--	--	7,024	2,842
Total hardwoods	--	--	--	--	3,512	14,683	10,860	--	--	--	29,055	11,758
All types	--	3,836	7,707	34,468	71,957	189,227	97,474	18,390	144,398	18,840	586,297	237,267

Table 10.--*Area of unproductive nonreserved forest land in the Bozeman Working Circle by forest type and ownership class, 1976*

Forest type	Ownership class					
	State		Private		State and private	
	Acres	Hectares	Acres	Hectares	Acres	Hectares
Douglas-fir	827	335	14,378	5,818	15,205	6,153
Ponderosa pine	486	197	7,150	2,893	7,636	3,090
Lodgepole pine	242	98	3,502	1,417	3,744	1,515
Whitebark-limber pine	376	152	7,050	2,853	7,426	3,005
Juniper	163	66	3,501	1,417	3,664	1,483
Mixed softwoods	260	105	6,888	2,788	7,148	2,893
Aspen	330	133	7,079	2,865	7,409	2,998
Cottonwood	520	210	6,503	2,632	7,023	2,842
Mixed hardwoods	622	252	11,102	4,493	11,724	4,745
All types	3,826	1,548	67,153	27,176	70,979	28,724

Table 11.--*Number of growing stock trees on commercial timberland in the Bozeman Working Circle by species and diameter class; State and private, 1976*

Species	Diameter class (inches at breast height)														
	1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	All classes
	Thousand trees															
Douglas-fir	5,678	7,598	12,710	13,859	9,445	5,369	2,946	1,628	871	413	207	126	74	24	125	61,073
Ponderosa pine	219	349	271	484	215	173	82	88	54	20	11	6	4	--	9	1,985
Lodgepole pine	5,127	8,664	7,608	7,798	4,385	1,604	744	269	156	49	23	--	--	--	--	36,427
Whitebark-limber pine	345	1,347	1,591	1,541	1,022	803	361	266	59	34	35	4	--	--	--	7,408
Subalpine fir	10,367	4,937	4,190	2,645	1,024	496	144	75	26	7	5	--	8	--	--	23,924
Engelmann spruce	2,097	1,600	1,153	1,168	879	569	425	292	89	108	58	47	--	14	10	8,509
Juniper	1,455	2,226	636	85	21	39	--	10	--	--	--	--	5	--	--	4,477
Total softwoods	25,288	26,721	28,159	27,580	16,991	9,053	4,702	2,628	1,255	631	339	183	91	38	144	143,803
Aspen	118	780	1,139	927	417	203	39	--	--	--	--	--	--	--	--	3,623
Other hardwoods	--	105	57	193	264	35	63	20	8	14	11	9	4	4	5	792
Total hardwoods	118	885	1,196	1,120	681	238	102	20	8	14	11	9	4	4	5	4,415
All species	25,406	27,606	29,355	28,700	17,672	9,291	4,804	2,648	1,263	645	350	192	95	42	149	148,218

Table 12.--*Number of cull and salvable dead trees on commercial timberland in the Bozeman Working Circle by ownership class, and softwoods and hardwoods, 1976*

Ownership class and species group	Cull trees			Salvable dead trees
	Sound	Rotten	Total	
	- - - - - - - - - - *Thousand trees*	- - - - - - - - - -		
State:				
Softwoods	1,769	51	1,820	569
Hardwoods	140	14	154	34
Total	1,909	65	1,974	603
Private:				
Softwoods	38,477	957	39,434	12,561
Hardwoods	2,401	235	2,636	476
Total	40,878	1,192	42,070	13,037
State and private:				
Softwoods	40,246	1,008	41,254	13,130
Hardwoods	2,541	249	2,790	510
Total	42,787	1,257	44,044	13,640

Table 13.--*Net volume of growing stock on commercial timberland in the Bozeman Working Circle by ownership class, forest type, and stand-size class, 1976*

Ownership class	Forest type	Stand-size class				All classes	
		Sawtimber	Poletimber	Sapling/seedling	Nonstocked		
		Thousand cubic feet					*Thousand cubic meters*
State:							
	Douglas-fir	18,848	2,848	64	--	21,760	617
	Ponderosa pine	393	--	--	--	393	11
	Lodgepole pine	6,967	3,849	18	41	10,875	308
	Whitebark-limber pine	3,048	--	14	--	3,062	87
	Spruce-subalpine fir	5,509	311	151	--	5,971	169
	Juniper	35	--	3	--	38	1
	Aspen	--	924	319	--	1,243	35
	Cottonwood	280	189	--	--	469	13
	All types	35,080	8,121	569	41	43,811	1,241
Private:							
	Douglas-fir	386,081	63,999	2,107	--	452,187	12,804
	Ponderosa pine	10,895	--	--	--	10,895	309
	Lodgepole pine	138,218	72,992	3,045	886	215,141	6,092
	Whitebark-limber pine	56,029	--	291	--	56,320	1,594
	Spruce-subalpine fir	112,558	10,402	3,941	940	127,841	3,620
	Juniper	2,431	--	69	--	2,500	71
	Aspen	--	11,552	4,083	--	15,635	443
	Cottonwood	3,493	2,367	--	--	5,860	166
	All types	709,705	161,312	13,536	1,826	886,379	25,099
State and private:							
	Douglas-fir	404,929	66,847	2,171	--	473,947	13,421
	Ponderosa pine	11,288	--	--	--	11,288	320
	Lodgepole pine	145,185	76,841	3,063	927	226,016	6,400
	Whitebark-limber pine	59,077	--	305	--	59,382	1,681
	Spruce-subalpine fir	118,067	10,713	4,092	940	133,812	3,789
	Juniper	2,466	--	72	--	2,538	72
	Aspen	--	12,476	4,402	--	16,878	478
	Cottonwood	3,773	2,556	--	--	6,329	179
	All types	744,785	169,433	14,105	1,867	930,190	26,340

Table 14.--*Net volume of sawtimber on commercial timberland in the Bozeman Working Circle by ownership class, forest type, and stand-size class, 1976*

Ownership class	Forest type	Stand-size class				All classes
		Sawtimber	Poletimber	Sapling/seedling	Nonstocked	
		Thousand board feet[1]				
State:						
	Douglas-fir	73,626	4,343	141	--	78,110
	Ponderosa pine	1,540	--	--	--	1,540
	Lodgepole pine	26,347	4,126	52	126	30,651
	Whitebark-limber pine	10,810	--	39	--	10,849
	Spruce-subalpine fir	21,036	731	469	--	22,236
	Juniper	85	--	2	--	87
	Aspen	--	657	1,487	--	2,144
	Cottonwood	723	458	--	--	1,181
	All types	134,167	10,315	2,190	126	146,798
Private:						
	Douglas-fir	1,491,894	98,531	6,278	--	1,596,703
	Ponderosa pine	42,945	--	--	--	42,945
	Lodgepole pine	509,264	76,468	986	2,698	589,416
	Whitebark-limber pine	200,787	--	844	--	201,631
	Spruce-subalpine fir	430,699	24,476	12,204	3,762	471,141
	Juniper	5,942	--	39	--	5,981
	Aspen	--	8,203	19,073	--	27,276
	Cottonwood	9,031	5,726	--	--	14,757
	All types	2,690,562	213,404	39,424	6,460	2,949,850
State and private:						
	Douglas-fir	1,565,520	102,874	6,419	--	1,674,813
	Ponderosa pine	44,485	--	--	--	44,485
	Lodgepole pine	535,611	80,594	1,038	2,824	620,067
	Whitebark-limber pine	211,597	--	883	--	212,480
	Spruce-subalpine fir	451,735	25,207	12,673	3,762	493,377
	Juniper	6,027	--	41	--	6,068
	Aspen	--	8,860	20,560	--	29,420
	Cottonwood	9,754	6,184	--	--	15,938
	All types	2,824,729	223,719	41,614	6,586	3,096,648

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[1] International 1/4-inch rule.

Table 15.--*Net volume of growing stock on commercial timberland in the Bozeman Working Circle by species and diameter class; State and private, 1976*

Species	Diameter class (inches at breast height)												
	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	All classes
	Thousand cubic feet													
Douglas-fir	34,167	70,846	82,379	71,410	55,626	41,213	28,434	17,004	10,662	7,584	5,275	2,217	15,752	442,569
Ponderosa pine	420	2,036	1,706	2,119	1,593	2,269	1,854	1,061	489	313	295	--	1,082	15,237
Lodgepole pine	38,883	69,563	62,576	33,494	21,928	9,494	7,163	2,501	1,492	--	--	--	--	247,094
Whitebark-limber pine	5,422	10,818	10,411	13,161	7,675	7,771	2,053	1,743	1,728	239	--	--	--	61,021
Subalpine fir	16,168	17,420	11,447	7,927	3,379	2,276	1,039	377	291	--	536	--	--	60,860
Engelmann spruce	4,187	7,687	9,746	10,962	11,808	10,402	4,117	6,742	4,222	4,289	--	1,739	1,607	77,508
Juniper	305	148	95	210	--	136	--	--	--	--	15	--	--	909
Total softwoods	99,552	178,518	178,360	139,283	102,009	73,561	44,660	29,428	18,884	12,425	6,121	3,956	18,441	905,198
Aspen	3,501	6,123	4,165	2,862	801	--	--	--	--	--	--	--	--	17,452
Cottonwood	108	890	1,983	433	1,003	613	198	420	531	409	279	211	462	7,540
Total hardwoods	3,609	7,013	6,148	3,295	1,804	613	198	420	531	409	279	211	462	24,992
All species	103,161	185,531	184,508	142,578	103,813	74,174	44,858	29,848	19,415	12,834	6,400	4,167	18,903	930,190

Table 16.--*Net volume of sawtimber on commercial timberland in the Bozeman Working Circle by species and diameter class; State and private, 1976*

Species	Diameter class (inches at breast height)											
	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	All classes
	Thousand board feet, International 1/4-inch rule											
Douglas-fir	285,937	329,895	280,334	217,482	154,290	94,016	59,722	42,686	29,770	12,685	90,995	1,597,812
Ponderosa pine	4,983	8,639	7,725	11,690	9,815	5,539	2,943	1,703	1,589	--	5,519	60,145
Lodgepole pine	255,959	194,256	125,789	53,161	39,265	13,558	8,145	--	--	--	--	690,133
Whitebark-limber pine	43,320	75,873	43,719	43,321	11,165	9,443	9,384	1,319	--	--	--	237,544
Subalpine fir	44,229	41,322	17,793	11,904	5,411	1,968	1,528	--	3,016	--	--	127,171
Engelmann spruce	40,480	59,780	63,973	55,565	21,774	35,358	22,201	23,243	--	10,054	9,611	342,039
Juniper	286	628	--	385	--	--	--	--	41	--	--	1,340
Total softwoods	675,194	710,393	539,333	393,508	241,720	159,882	103,923	68,951	34,416	22,739	106,125	3,056,184
Aspen	0	14,684	4,102	--	--	--	--	--	--	--	--	18,786
Cottonwood	0	2,188	5,007	3,030	949	1,972	2,422	1,822	1,250	938	2,100	21,678
Total hardwoods	0	16,872	9,109	3,030	949	1,972	2,422	1,822	1,250	938	2,100	40,464
All species	675,194	727,265	548,442	396,538	242,669	161,854	106,345	70,773	35,666	23,677	108,225	3,096,648

Table 17.--*Net volume of growing stock and sawtimber on commercial timberland in the Bozeman Working Circle by ownership class and species, 1976*

Ownership class	Species											All species
	Douglas-fir	Ponderosa pine	Lodgepole pine	Whitebark-limber pine	Subalpine fir	Engelmann spruce	Juniper	Total softwoods	Aspen	Cottonwood	Total hardwoods	
	GROWING STOCK											
	Thousand cubic feet											
State	20,206	504	11,819	3,005	2,877	3,677	21	42,109	1,181	521	1,702	43,811
Private	422,363	14,733	235,275	58,016	57,983	73,831	888	863,089	16,271	7,019	23,290	886,379
Total	442,569	15,237	247,094	61,021	60,860	77,508	909	905,198	17,452	7,540	24,992	930,190
	GROWING STOCK											
	Thousand cubic meters											
State	572	14	335	85	81	104	1	1,192	34	15	49	1,241
Private	11,960	417	6,662	1,643	1,642	2,091	25	24,440	460	199	659	25,099
Total	12,532	431	6,997	1,728	1,723	2,195	26	25,632	494	214	708	26,340
	SAWTIMBER											
	Thousand board feet, International 1/4-inch rule											
State	74,413	1,975	33,960	11,496	6,147	16,171	21	144,183	1,189	1,426	2,615	146,798
Private	1,523,399	58,170	656,173	226,048	121,024	325,868	1,319	2,912,001	17,597	20,252	37,849	2,949,850
Total	1,597,812	60,145	690,133	237,544	127,171	342,039	1,340	3,056,184	18,786	21,678	40,464	3,096,648

Table 18.--*Net volume of timber on commercial timberland in the Bozeman Working Circle by class of timber, and softwoods and hardwoods; State and private, 1976*

Class of timber	Softwoods	Hardwoods	All classes
	- - - - - - *Thousand cubic feet* - - - - - -		
Sawtimber trees:			
Saw-log portion	552,660	6,276	558,936
Upper-stem portion	74,468	1,946	76,414
Total	627,128	8,222	635,350
Poletimber trees	278,070	16,770	294,840
All growing stock trees	905,198	24,992	930,190
Sound cull trees	24,825	1,455	26,280
Rotten cull trees	2,959	162	3,121
Salvable dead trees	71,869	1,881	73,750
All timber	1,004,851	28,490	1,033,341

Table 19.--*Net volume of growing stock on commercial timberland in the Bozeman Working Circle by forest type and species; State and private, 1976*

Forest type	Species											All species	
	Douglas-fir	Ponderosa pine	Lodgepole pine	Whitebark-limber pine	Subalpine fir	Engelmann spruce	Juniper	Total softwoods	Aspen	Cottonwood	Total hardwoods		
	- - - - - - *Thousand cubic feet* - - - - - -												*Thousand cubic meters*
Douglas-fir	417,655	4,197	36,888	6,828	1,514	2,490	163	469,735	4,212	--	4,212	473,947	13,421
Ponderosa pine	248	11,040	--	--	--	--	--	11,288	--	--	--	11,288	320
Lodgepole pine	10,926	--	191,239	4,975	11,548	7,102	--	225,790	226	--	226	226,016	6,400
Whitebark-limber pine	2,655	--	4,892	32,584	9,800	9,451	--	59,382	--	--	--	59,382	1,681
Spruce-subalpine fir	6,556	--	13,486	16,634	37,998	57,927	--	132,601	--	1,211	1,211	133,812	3,789
Juniper	1,792	--	--	--	--	--	746	2,538	--	--	--	2,538	72
Aspen	2,737	--	589	--	--	538	--	3,864	13,014	--	13,014	16,878	478
Cottonwood	--	--	--	--	--	--	--	--	--	6,329	6,329	6,329	179
All types	442,569	15,237	247,094	61,021	60,860	77,508	909	905,198	17,452	7,540	24,992	930,190	26,340
	- - - - - - *Thousand cubic meters* - - - - - -												
All types	12,532	431	6,997	1,728	1,723	2,195	26	25,632	494	214	708	--	26,340

Table 21.--*Net volume of sawtimber on commercial timberland in the Bozeman Working Circle by forest type and species; State and private; 1976*

Forest type	Species: Douglas-fir	Ponderosa pine	Lodgepole pine	Whitebark-limber pine	Subalpine fir	Engelmann spruce	Juniper	Total softwoods	Aspen	Cottonwood	Total hardwoods	All species
	Thousand board feet, International 1/4-inch rule											
Douglas-fir	1,497,572	16,814	116,018	17,417	7,959	9,789	--	1,665,569	9,244	--	9,244	1,674,813
Ponderosa pine	1,154	43,331	--	--	--	--	--	44,485	--	--	--	44,485
Lodgepole pine	36,425	--	515,162	18,756	16,589	33,135	--	620,067	--	--	--	620,067
Whitebark-limber pine	13,340	--	19,254	130,884	17,471	31,531	--	212,480	--	--	--	212,480
Spruce-subalpine fir	30,854	--	36,422	70,487	85,152	264,722	--	487,637	--	5,740	5,740	493,377
Juniper	4,728	--	--	--	--	--	1,340	6,068	--	--	--	6,068
Aspen	13,739	--	3,277	--	--	2,862	--	19,878	9,542	--	9,542	29,420
Cottonwood	--	--	--	--	--	--	--	--	--	15,938	15,938	15,938
All types	1,597,812	60,145	690,133	237,544	127,171	342,039	1,340	3,056,184	18,786	21,678	40,464	3,096,648

Table 20.--*Net annual growth of growing stock and sawtimber on commercial timberland in the Bozeman Working Circle by ownership class and species, 1976*

Ownership class	Species: Douglas-fir	Ponderosa pine	Lodgepole pine	Whitebark-limber pine	Subalpine fir	Engelmann spruce	Total softwoods	Aspen	Cottonwood	Total hardwoods	All species
	GROWING STOCK										
	Cubic feet										
State	329,778	11,101	73,005	40,858	41,955	38,052	534,749	21,136	15,344	36,480	571,229
Private	6,778,305	281,597	1,404,056	825,824	960,636	825,190	11,075,608	361,315	162,572	523,887	11,599,495
Total	7,108,083	292,698	1,477,061	866,682	1,002,591	863,242	11,610,357	382,451	177,916	560,367	12,170,724
	GROWING STOCK										
	Cubic meters										
State	9,338	314	2,068	1,157	1,188	1,077	15,142	599	434	1,033	16,175
Private	191,940	7,974	39,758	23,385	27,202	23,367	313,626	10,231	4,604	14,835	328,461
Total	201,278	8,288	41,826	24,542	28,390	24,444	328,768	10,830	5,038	15,868	344,636
	SAWTIMBER										
	Board feet, International 1/4-inch rule										
State	2,116,053	51,056	446,577	115,509	38,367	252,041	3,019,603	121,398	9,088	130,486	3,150,089
Private	41,531,104	1,250,863	7,639,784	2,125,074	767,805	5,746,687	59,061,317	1,542,177	-40,391	1,501,786	60,563,103
Total	43,647,157	1,301,919	8,086,361	2,240,583	806,172	5,998,728	62,080,920	1,663,575	-31,303	1,632,272	63,713,192

Table 22.--*Annual mortality of growing stock and sawtimber on commercial timberland in the Bozeman Working Circle by ownership class, and softwoods and hardwoods, 1976*

Species group and ownership class	Growing stock		Sawtimber
	- *Cubic feet* -	- *Cubic meters* -	- *Board feet*[1] -
Softwoods:			
State	256,188	7,254	826,753
Private	5,025,272	142,300	16,680,465
Total	5,281,460	149,554	17,507,218
Hardwoods:			
State	24,244	687	36,355
Private	376,567	10,663	660,059
Total	400,811	11,350	696,414

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[1] International 1/4-inch rule.

Bozeman Working Circle by cause of death and species; State and private, 1976

Cause of death	Species								All species
	Douglas-fir	Lodgepole pine	Subalpine fir	Engelmann spruce	Total softwoods	Aspen	Cottonwood	Total hardwoods	
					GROWING STOCK *Cubic feet*				
Insects	268,064	210,500	284,637	--	763,201	--	--	--	763,201
Disease	74,391	81,537	--	--	155,928	47,164	--	47,164	203,092
Fire	56,997	63,997	--	--	120,994	--	--	--	120,994
Animal	--	--	--	--	--	--	--	--	--
Weather	640,434	725,327	189,275	173,420	1,728,456	--	45,404	45,404	1,773,860
Suppression	220,850	90,568	--	--	311,418	28,349	--	28,349	339,767
Unknown	256,454	1,453,776	339,531	151,702	2,201,463	162,618	117,276	279,894	2,481,357
Logging	--	--	--	--	--	--	--	--	--
Total	1,517,190	2,625,705	813,443	325,122	5,281,460	238,131	162,680	400,811	5,682,271
					GROWING STOCK *Cubic meters*				
Insects	7,591	5,961	8,060	--	21,612	--	--	--	21,612
Disease	2,107	2,309	--	--	4,416	1,335	--	1,335	5,751
Fire	1,614	1,812	--	--	3,426	--	--	--	3,426
Animal	--	--	--	--	--	--	--	--	--
Weather	18,135	20,539	5,360	4,910	48,944	--	1,286	1,286	50,230
Suppression	6,253	2,565	--	--	8,818	803	--	803	9,621
Unknown	7,262	41,166	9,614	4,296	62,338	4,605	3,321	7,926	70,264
Logging	--	--	--	--	--	--	--	--	--
Total	42,962	74,352	23,034	9,206	149,554	6,743	4,607	11,350	160,904
					SAWTIMBER *Board feet, International 1/4-inch rule*				
Insects	797,525	820,142	965,244	--	2,582,911	--	--	--	2,582,911
Disease	137,643	244,952	--	--	382,595	--	--	--	382,595
Fire	--	192,183	--	--	192,183	--	--	--	192,183
Animal	--	--	--	--	--	--	--	--	--
Weather	2,776,926	1,799,923	624,475	927,333	6,128,657	--	210,098	210,098	6,338,755
Suppression	155,419	--	--	--	155,419	--	--	--	155,419
Unknown	1,206,654	6,044,033	--	814,766	8,065,453	--	486,316	486,316	8,551,769
Logging	--	--	--	--	--	--	--	--	--
Total	5,074,167	9,101,233	1,589,719	1,742,099	17,507,218	--	696,414	696,414	18,203,632

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MERCHANTABLE CUBIC STAND VOLUME CONVERSION FACTORS FOR LODGEPOLE PINE IN MONTANA AND IDAHO

Dennis M. Cole[1]

ABSTRACT

To accommodate the trend toward complete or near-complete utilization of lodgepole pine stems, merchantable cubic volume conversion factors were determined for a range of merchantable d.b.h. and top diameter limits. When used with either the accompanying stand volume equation or table, total volume and merchantable cubic stand volume estimates are easily obtained from field data. Instructions are given for obtaining appropriate data and how to apply them for field estimates of total cubic volume and merchantable cubic volume.

KEYWORDS: stand volume estimation, merchantable volume conversion factors, stand volume table, lodgepole pine

Stand volume equations and tables provide a means for quickly and reliably estimating timber volumes. Foresters can easily obtain and work-up in the field the necessary data on stand height and basal area, and using a stand volume equation or table, quickly compute total stand volume. When accompanied by merchantable volume conversion factors, stand volume equations and tables become even more useful. The author previously developed an equation and table for computing total cubic-foot volume of lodgepole pine stands in Montana and Idaho (Cole 1971), with factors for converting to merchantable cubic volume for utilization to 3-inch (7.6-cm) and 4-inch (10.2-cm) tops.

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Since then, developments in the lodgepole pine fiber and roundwood markets have increased the need for merchantable volume conversion factors for other utilization standards. Among these developments are the continued demand for lodgepole pine fenceposts and corral poles, the expansion of the house log market, the specific merchantability limits of the power pole industry, and the lower top utilization limits brought about by inwoods and mill-site chippers. The purpose of this note, then, is to present a more comprehensive set of merchantable volume conversion factors for use with the lodgepole pine stand volume equation or table.

DEVELOPMENT

For convenience, the earlier-developed stand volume equation is presented here:

$$V_T = 0.46952\ (BH) - 32.79$$

$$r^2 = 0.995$$

$$S_{y.x} = 82.9\ \text{ft}^3\text{/acre (2.4 percent of the mean)}$$

where:

V_T = Gross volume in cubic feet per acre of all trees greater than 4.5 feet (1.37 m) in height.

B = Basal area per acre in square feet.

H = Average height of dominant trees in feet.

This equation will be most useful to those having need for a large number of stand volume solutions--as in computer processing applications.

> Caution:--The above equation was developed in English units; hence the equation is applicable only to English units; i.e., basal area in square feet per acre and average height in feet of dominant trees. Upon solution of the stand volume equation in English units, the volume estimate can be converted to metric equivalents and merchantable volume conversion factors can be applied as discussed below.

For convenience of field or occasional use, a stand volume table based on the above equation is presented in table 1 for representative classes of stand basal areas and average heights of dominant trees. Notice that metric equivalents are included in this table, hence the table can be entered (with interpolation for specific basal area and height values as required) to obtain stand volumes in either British or metric units.

Volume conversion factors for lodgepole pine were earlier found to be strongly related to average stand diameter (Myers 1967; Cole 1971). For applications to point-sample cruising, however, the *mean* diameter of trees in the basal area sample is more appropriate because it can be easily obtained by measuring diameters of trees counted in the point sample (Stage 1962). This is discussed further in the application section of this paper.

Factors for conversion of total stand volume (from the equation or table 1) to merchantable cubic feet per acre were determined graphically by plotting ratios of merchantable[2] to total stand volume over the mean stand diameters, obtained from 125

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[2] Merchantable stand volumes were based on application of Honer's (1967) volume distribution function for lodgepole pine trees.

Table 1.--*Stand volume table for lodgepole pine in Montana and Idaho* [1]

Basal Area ft^2/ac (m^2/ha)	Average height of dominant trees Feet (Meters) 10 (3.05)	20 (6.10)	30 (9.14)	40 (12.19)	50 (15.24)	60 (18.29)	70 (21.34)	80 (24.38)	90 (27.43)	100 (30.48)
	Stand volume in total cubic feet per acre (m^3/ha) [2]									
30 (6.9)	108 (7.6)	249 (17.4)	390 (27.3)	531 (37.2)	671 (47.0)					
50 (1.5)	202 (14.1)	437 (30.6)	671 (47.0)	906 (63.4)	1,141 (79.8)	1,376 (96.3)				
70 (16.1)	296 (20.7)	625 (43.7)	953 (66.7)	1,282 (89.7)	1,611 (112.7)	1,939 (135.7)	2,268 (158.7)	2,597 (181.7)		
90 (20.7)	390 (27.3)	812 (56.8)	1,235 (86.4)	1,657 (115.9)	2,080 (145.5)	2,503 (175.1)	2,925 (204.7)	3,348 (234.3)	3,770 (263.8)	
110 (25.3)	484 (33.9)	1,000 (70.0)	1,517 (106.1)	2,033 (142.3)	2,550 (178.4)	3,066 (214.5)	3,583 (250.7)	4,099 (286.8)	4,615 (322.9)	5,132 (359.1)
130 (29.8)		1,188 (83.1)	1,798 (125.8)	2,409 (168.6)	3,019 (211.2)	3,629 (253.9)	4,240 (296.7)	4,850 (339.4)	5,461 (382.1)	6,071 (424.8)
150 (34.4)		1,376 (96.3)	2,080 (145.5)	2,784 (194.8)	3,489 (244.1)	4,193 (293.4)	4,897 (342.7)	5,601 (341.9)	6,306 (441.2)	7,010 (490.5)
170 (39.0)		1,564 (109.4)	2,362 (165.3)	3,160 (221.1)	3,958 (277.0)	4,756 (332.8)	5,555 (388.7)	6,353 (444.5)	7,151 (500.4)	7,949 (556.2)
190 (43.6)		1,751 (122.5)	2,643 (184.9)	3,536 (247.4)	4,428 (309.8)	5,320 (372.3)	6,212 (434.7)	7,104 (497.1)	7,996 (559.5)	
210 (48.2)		1,939 (135.7)	2,925 (204.7)	3,911 (273.7)	4,897 (342.7)	5,883 (411.6)	6,869 (480.6)	7,855 (549.6)	8,841 (618.6)	
230 (52.8)			3,207 (224.4)	4,287, (300.0)	5,367 (375.5)	6,447 (451.1)	7,526 (526.6)	8,606 (602.2)		
250 (57.4)			3,489 (244.1)	4,662 (326.2)	5,836 (408.4)	7,010 (490.5)	8,184 (572.7)	9,358 (654.8)		
270 (62.0)			3,770 (263.8)	5,038 (352.5)	6,306 (441.2)	7,573 (529.9)	8,841 (618.6)			
290 (66.6)			4,052 (283.5)	5,414 (378.8)	6,775 (474.1)					

[1] Block indicates extent of basic data from 125 stands, ages 22 to 125 years.

[2] Stand volume includes stem volume of all trees larger than 0.5 inch (1.27 cm) d.b.h

permanent sample plots in Montana and Idaho.[3] An example of the nature of this strong relationship is given in figure 1, for stand volumes in trees larger than 4.5 inches (11.4 cm) d.b.h. to a 4-inch (10.2-cm) top. All plottings for the various minimum diameters and top utilization combinations showed tight grouping of data points along the fitted lines as shown in figure 1; however, separate curves were obviously involved with each combination.

Table values of ratios were read from each curve for an appropriate set of mean stand diameters. They are presented as tables 2 through 7 for minimum merchantable diameters at breast height of 2.6, 4.6, and 6.6 inches (6.5, 11.7, and 16.8 cm) and top utilization limits of 1, 2, 3, 4, 5, and 6 inches (2.5, 5.1, 7.6, 10.2, 12.7, and 15.2 cm) diameter inside bark (d.i.b.).

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[3] Details of methods used for equation development can be found in the previous publication (Cole 1971).

APPLICATION

Total gross cubic-foot volume per acre of a stand is estimated by either of two approaches: (1) by referring to table 1, the stand volume table, or (2) by obtaining stand basal area in square feet per acre, average height of dominant trees in feet, and substituting these values into the lodgepole pine stand volume equation (page 2). In the latter approach, volume in metric units can be obtained by multiplying the volume in cubic feet per acre by 0.0699726 to obtain cubic meters per hectare.

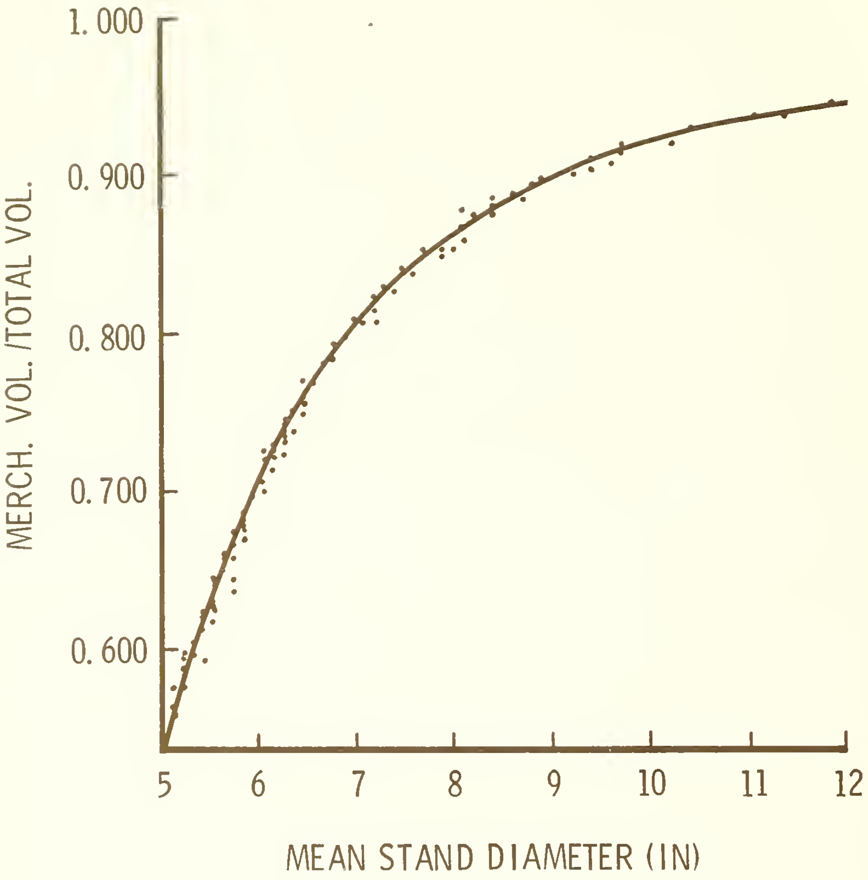

Figure 1.--Ratios of merchantable volume to total cubic volume over mean stand diameters for trees ≥ 4.6 inches (11.7 cm) d.b.h. (Merchantable volume was calculated for a stump height of 0.5 foot (0.15 m) and a minimum top diameter of 4 inches (19.2 cm), inside bark, using Honer's (1967) volume distribution function for lodgepole pines.)

Basal area per acre can be determined from a diameter tally of fixed-radius plots, or from variable-radius plots using an angle gage or wedge prism. The latter method is recommended for efficiency

For variable-plot cruising, an angle factor should be chosen to give about seven "count" trees per point. Generally, an angle factor of 10 will give satisfactory results. Only those trees with diameters larger than the minimum size of interest should be included in the point tally.

When merchantable cubic-foot volume is desired, it is also necessary to measure and record the d.b.h. of "count" trees of the sizes of interest at each sample point to obtain mean diameter for use with tables 2 through 7. Mean diameter ($\bar{D}$) for variable-radius plots is calculated with the formula (Stage 1962):

$$\bar{D} = \Sigma d_i^3/\Sigma d_i^2$$

where d = d.b.h. of individual tree in the point sample,

i = 1 to n, and

n = the number of "count" trees in the point sample.

Tables 2 through 7 can also be used with fixed-plot data by calculating both basal area per acre and arithmetic mean d.b.h. from the fixed plot d.b.h. tally.

Height of average dominant trees should be measured to the nearest foot at each variable-plot sampling point. One or two height measurements per plot will furnish a representative height of dominant trees if the cruise is adequate for sampling basal area. To avoid overestimates of volume resulting from the tendency to measure outstandingly tall trees in the stand, one should scan surrounding trees and select one or two "average-appearing" dominants for height measurements. These heights will then be comparable to the "10-tree" average dominant heights used in the development of the stand volume equation.

Determination of sample size is a sampling problem dependent on the stand variability and degree of precision desired. Where experience in similar stands is lacking, a preliminary survey to estimate basal area variation is recommended; then a suitable sample size can be determined in the conventional manner.

To obtain merchantable gross cubic volume per unit area, for either the English or metric system, multiply the estimate of total cubic volume by the appropriate merchantable volume conversion factor (ratio). The conversion factor is found in the appropriate table for the minimum included d.b.h. (tables 2 through 7), by looking up the ratio for the mean diameter of the subject stand, under the appropriate column for top diameter inside bark. To illustrate, suppose a stand is found to have a mean diameter of 10.0 inches (25.4 cm) and a gross total volume of 6,490 ft^3/acre (454.1 m^3/ha). It is desired to find the gross merchantable cubic volume included in all trees 4.6 inches (11.7 cm) d.b.h. and larger when utilized to a 2-inch (5.1-cm) top diameter inside bark. Table 3 provides the conversion factors for these d.b.h. and top diameter limits. Examining it we find in the column for a 2-inch (5.1-cm) top, that the merchantable conversion factor for an average stand diameter of 10.0 inches (25.4 cm) is 0.958. Multiplying the gross total cubic stand volume estimate by this factor gives us the gross merchantable cubic volume per unit area of the stand:

6,490 ft^3/ac × *0.958* = *6,217* ft^3/acre

or

454.1 m^3/ha × *0.958* = *435.0* m^3/hectare.

Table 2.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees ≥ 2.6 inches (6.5 cm) d.b.h.; with top utilization limits of 1.0 inch (2.5 cm) and 2.0 inches (5.1 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume		Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	1-inch top (2.5-cm)	2-inch top (5.1-cm)		1-inch top (2.5-cm)	2-inch top (5.1-cm)
3.0 (7.6)	0.941	0.739	5.5 (14.0)	0.959	0.924
3.1 (7.9)	.943	.760	5.6 (14.2)	--	.926
3.2 (8.1)	.944	.777	5.7 (14.5)	--	.928
3.3 (8.4)	.945	.791	5.8 (14.7)	--	.930
3.4 (8.6)	.946	.803	5.9 (15.0)	--	.932
3.5 (8.9)	.947	.815	6.0 (15.2)	.960	.934
3.6 (9.1)	.948	.823	6.2 (15.8)	--	.936
3.7 (9.4)	.949	.830	6.4 (16.3)	--	.938
3.8 (9.7)	.950	.837	6.5 (16.5)	.961	--
3.9 (9.9)	.951	.844	6.6 (16.8)	--	.940
4.0 (10.2)	.952	.850	6.8 (17.3)	--	.942
4.1 (10.4)	--	.856	7.0 (17.8)	.962	.944
4.2 (10.7)	.954	.862	7.2 (18.3)	--	.946
4.3 (10.9)	--	.868	7.4 (18.8)	--	.947
4.4 (11.2)	.955	.874	7.6 (19.3)	--	.948
4.5 (11.4)	--	.880	7.8 (19.8)	--	.949
4.6 (11.7)	.956	.886	8.0 (20.3)	.963	.950
4.7 (11.9)	--	.892	8.5 (21.6)	--	.952
4.8 (12.2)	.957	.897	9.0 (22.9)	.964	.954
4.9 (12.5)	--	.902	9.5 (24.1)	--	.955
5.0 (12.7)	.958	.907	10.0 (25.4)	.964	.956
5.1 (13.0)	--	.911	10.5 (26.7)	--	.957
5.2 (13.2)	--	.915	11.0 (27.9)	.965	.958
5.3 (13.5)	--	.918	11.5 (29.2)	--	.959
5.4 (13.7)	--	.921	12.0 (30.5)	.965	.960

Table 3.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees ≥ 4.6 inches (11.7 cm) d.b.h.; with top utilization limits of 1.0 inch (2.5 cm) and 2.0 inches (5.1 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	1-inch top (2.5-cm)	2-inch top (5.1-cm)
5.0 (12.7)	0.959	0.923
5.1 (13.0)	--	.925
5.2 (13.2)	--	.927
5.3 (13.5)	--	.929
5.4 (13.7)	--	.931
5.5 (14.0)	.960	.933
5.6 (14.2)	--	.934
5.7 (14.5)	--	.935
5.8 (14.7)	--	.936
5.9 (15.0)	--	.937
6.0 (15.2)	.961	.938
6.1 (15.5)	--	.939
6.2 (15.8)	--	.940
6.3 (16.0)	--	.941
6.4 (16.3)	--	.942
6.5 (16.5)	--	.943
6.6 (16.8)	--	.944
6.7 (17.0)	--	.945
6.8 (17.3)	--	0.946
6.9 (17.5)	--	.946
7.0 (17.8)	0.962	.947
7.2 (18.3)	--	.948
7.4 (18.8)	--	.949
7.6 (19.3)	--	.950
7.8 (19.8)	--	.951
8.0 (20.3)	.963	.952
8.2 (20.8)	--	.953
8.4 (21.3)	--	.953
8.6 (21.8)	--	.954
8.8 (22.4)	--	.955
9.0 (22.9)	.964	.955
9.5 (24.1)	--	.957
10.0 (25.4)	.964	.958
10.5 (26.7)	--	.959
11.0 (27.9)	.965	.960
12.0 (30.5)	.965	.961

Table 4.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees ≥ 4.6 inches (11.7 cm) d.b.h.; with top utilization limits of 3.0 inches (7.6 cm) and 4.0 inches (10.2 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	3-inch top (7.6-cm)	4-inch top (10.2-cm)
5.0 (12.7)	0.809	0.536
5.1 (13.0)	.818	.560
5.2 (13.2)	.826	.583
5.3 (13.5)	.834	.603
5.4 (13.7)	.841	.621
5.5 (14.0)	.846	.637
5.6 (14.2)	.851	.652
5.7 (14.5)	.856	.666
5.8 (14.7)	.861	.679
5.9 (15.0)	.866	.692
6.0 (15.2)	.870	.705
6.1 (15.5)	.874	.717
6.2 (15.8)	.878	.729
6.3 (16.0)	.882	.740
6.4 (16.3)	.886	.751
6.5 (16.5)	.890	.761
6.6 (16.8)	.893	.771
6.7 (17.0)	.896	.779
6.8 (17.3)	.899	.787
6.9 (17.5)	.902	.794
7.0 (17.8)	.904	.801
7.1 (18.0)	.906	.807
7.2 (18.3)	.908	.813
7.3 (18.5)	.910	.819
7.4 (18.8)	.912	.824
7.5 (19.0)	.914	.829
7.6 (19.3)	.916	.834
7.7 (19.6)	.918	.839
7.8 (19.8)	.920	.843
7.9 (20.1)	.922	.847
8.0 (20.3)	.923	.851
8.1 (20.6)	--	.855
8.2 (20.8)	.926	.859
8.3 (21.1)	--	.863
8.4 (21.3)	.928	.867
8.5 (21.6)	--	.871
8.6 (21.8)	0.930	0.875
8.7 (22.1)	--	.879
8.8 (22.4)	.932	.882
8.9 (22.6)	--	.885
9.0 (22.9)	.934	.888
9.1 (23.1)	--	.891
9.2 (23.4)	.936	.894
9.3 (23.6)	--	.897
9.4 (23.9)	.938	.900
9.5 (24.1)	--	.903
9.6 (24.4)	.940	.906
9.7 (24.6)	--	.909
9.8 (24.9)	.942	.911
9.9 (25.2)	--	.913
10.0 (25.4)	.944	.915
10.1 (25.7)	--	.917
10.2 (25.9)	--	.918
10.3 (26.2)	--	.919
10.4 (26.4)	--	.920
10.5 (26.7)	.947	.921
10.6 (26.9)	--	.922
10.7 (27.2)	--	.923
10.8 (27.4)	--	.924
10.9 (27.7)	--	.925
11.0 (27.9)	.950	.926
11.1 (28.2)	--	.927
11.2 (28.5)	--	.928
11.3 (28.7)	--	.929
11.4 (29.0)	--	.930
11.5 (29.2)	.951	.931
11.6 (29.5)	--	.932
11.7 (29.7)	--	.933
11.8 (30.0)	--	.934
11.9 (30.2)	--	.935
12.0 (30.5)	.952	.936

Table 5.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees ≥ 6.6 inches (16.8 cm) d.b.h.; with top utilization limits of 1.0 inch (2.5 cm) and 2.0 inches (5.1 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	1-inch top (2.5-cm)	2-inch top (5.1-cm)
7.0 (17.8)	0.963	0.949
7.1 (18.0)	.963	.950
7.3 (18.5)	.963	.951
7.5 (19.0)	.963	.952
7.7 (19.6)	.963	.953
8.0 (20.3)	.964	.954
8.5 (21.6)	.964	.955
9.0 (22.9)	.964	.956
9.5 (24.1)	.964	.957
10.0 (25.4)	.964	.958
10.5 (26.7)	.964	.959
11.0 (27.9)	.965	.960
12.0 (30.5)	.965	.961

Table 6.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees* $\geq$ *6.6 inches (16.8 cm) d.b.h.; with top utilization limits of 3.0 inches (7.6 cm) and 4.0 inches (10.2 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	3-inch top (7.6-cm)	4-inch top (10.2-cm)
7.0 (17.8)	0.912	0.828
7.1 (18.0)	.914	.835
7.2 (18.3)	.916	.842
7.3 (18.5)	.918	.848
7.4 (18.8)	.920	.853
7.5 (19.0)	.922	.857
7.6 (19.3)	.924	.861
7.7 (19.6)	.926	.865
7.8 (19.8)	.927	.868
7.9 (20.1)	.928	.871
8.0 (20.3)	.929	.874
8.1 (20.6)	.930	.877
8.2 (20.8)	.931	.880
8.3 (21.1)	.932	.883
8.4 (21.3)	.933	.886
8.5 (21.6)	.934	.889
8.6 (21.8)	.935	.892
8.7 (22.1)	.936	.894
8.8 (22.4)	.937	.896
8.9 (22.6)	.938	.898
9.0 (22.9)	.939	.900
9.1 (23.1)	.940	.902
9.2 (23.4)	.941	.904
9.3 (23.6)	--	.906
9.4 (23.9)	.942	.908
9.5 (24.1)	--	.910
9.6 (24.4)	0.943	0.912
9.7 (24.6)	--	.914
9.8 (24.9)	.944	.915
9.9 (25.2)	--	.916
10.0 (25.4)	.945	.917
10.1 (25.7)	--	.918
10.2 (25.9)	.946	.919
10.3 (26.2)	--	.920
10.4 (26.4)	.947	.921
10.5 (26.7)	--	.922
10.6 (26.9)	.948	.923
10.7 (27.2)	--	.924
10.8 (27.4)	.949	.925
10.9 (27.7)	--	.926
11.0 (27.9)	.950	.927
11.1 (28.2)	--	.928
11.2 (28.5)	--	.929
11.3 (28.7)	--	.930
11.4 (29.0)	--	.931
11.5 (29.2)	.951	.932
11.6 (29.5)	--	.933
11.7 (29.7)	--	.934
11.8 (30.0)	--	.935
11.9 (30.2)	--	.935
12.0 (30.5)	.952	.936

Table 7.--*Factors for conversion of total cubic stand volume to merchantable cubic stand volume for all trees ≥ 6.6 inches (16.8 cm) d.b.h.; with top utilization limits of 5.0 inches (12.7 cm) and 6.0 inches (15.2 cm) d.i.b., and stump heights of 0.5 foot (0.15 m)*

Mean stand diameter [inches (cm)]	Ratio of merchantable volume to total volume	
	5-inch top (12.7-cm)	6-inch top (15.2-cm)
7.0 (17.8)	0.668	0.391
7.1 (18.0)	.684	.427
7.2 (18.3)	.700	.463
7.3 (18.5)	.711	.484
7.4 (18.8)	.722	.505
7.5 (19.0)	.733	.521
7.6 (19.3)	.744	.537
7.7 (19.6)	.751	.552
7.8 (19.8)	.758	.566
7.9 (20.1)	.764	.580
8.0 (20.3)	.770	.593
8.1 (20.6)	.776	.606
8.2 (20.8)	.782	.618
8.3 (21.1)	.788	.630
8.4 (21.3)	.794	.642
8.5 (21.6)	.800	.653
8.6 (21.8)	.806	.664
8.7 (22.1)	.811	.675
8.8 (22.4)	.816	.686
8.9 (22.6)	.821	.697
9.0 (22.9)	.826	.706
9.1 (23.1)	.831	.714
9.2 (23.4)	.836	.722
9.3 (23.6)	.841	.730
9.4 (23.9)	.845	.738
9.5 (24.1)	.849	.746
9.6 (24.4)	0.853	0.754
9.7 (24.6)	.857	.762
9.8 (24.9)	.861	.770
9.9 (25.2)	.865	.778
10.0 (25.4)	.868	.785
10.1 (25.7)	.871	.791
10.2 (25.9)	.874	.796
10.3 (26.2)	.877	.801
10.4 (26.4)	.879	.806
10.5 (26.7)	.881	.811
10.6 (26.9)	.883	.816
10.7 (27.2)	.885	.821
10.8 (27.4)	.887	.826
10.9 (27.7)	.889	.830
11.0 (27.9)	.891	.834
11.1 (28.2)	.893	.837
11.2 (28.5)	.895	.840
11.3 (28.7)	.897	.843
11.4 (29.0)	.899	.846
11.5 (29.2)	.901	.849
11.6 (29.5)	.902	.852
11.7 (29.7)	.903	.854
11.8 (30.0)	.904	.856
11.9 (30.2)	.905	.858
12.0 (30.5)	.906	.860

Notice that the equations and tables presented here are in units of *gross* volume per unit area. No cull or defect allowances were involved in their development. To obtain realistic *net* volume estimates, users should make appropriate volume deductions for cull and defect on the basis of data and experience from stand surveys, scaling, and mill-defect studies.

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A COMPARISON OF PORTABLE ALUMINUM AND STANDARD WOODEN THERMOMETER SHELTERS

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ABSTRACT

Presents and discusses results of a field test of a new model portable aluminum thermometer shelter near Missoula, Montana. Comparisons of daily maximum and minimum temperatures show this shelter to be quite suitable as a field-use alternative to the standard wooden shelter employed at climatological and fire-weather stations.

KEYWORDS: temperature measurement, thermometer shelters, fire-weather equipment

A portable, collapsible, white-painted aluminum thermometer shelter has been an item of Forest Service, USDA, field equipment for about the past 15 years. This shelter, developed at the Northern Forest Fire Laboratory (NFFL), near Missoula, Montana, is described by the Forest Service, USDA (1964). Results of tests at several diverse locations were said to be generally satisfactory, considering the portability advantage and the sampling errors that may be encountered in field use. As compared with the wooden "cotton-region" shelter, which is the standard at climatological and fire-weather stations, the aluminum shelter gave daily maximum temperatures averaging mostly between 1.0° and 2.0°F (0.6° and 1.1°C) too high. The size of this assumed error, apparently resulting from absorption or reflection of solar radiation, was found to vary, overall, with the temperature or time of year. Minimum temperatures generally averaged a fraction of 1°F too low.

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A new model aluminum shelter was recently developed at the San Dimas Equipment Development Center in California. Aside from possible improvement in measuring air temperature, the new model is of sturdier construction (though only the floor is of thicker metal than before). This is largely a result of metal-framed panels of coarse-mesh wire screening fastened behind the louvered walls. There is also screening under the floor holes. The louvers themselves are somewhat closed, formed (stamped and pressed out) like those in the final specifications drawn for the earlier model. Some of the earlier shelters actually produced, however, have louvers with a more open, flared appearance. The interior of the newer shelter is unpainted, giving a grey, non-reflective property; the exterior has a glossy white enamel finish. Dimensions are identical to those of the earlier model, 2 by 2 by 2 ft (0.6 by 0.6 by 0.6 m), and the double roofing is about the same.

The new shelter was dispatched to the NFFL in July 1976, at which time comparisons were begun with a version of the earlier model and with two "cotton-region" shelters. This report evaluates the newer shelter, documenting and examining the results of at least one year's comparisons. A brief summary of the results is included in an article by William C. Fischer, submitted to "Fire Management Notes" (Forest Service, USDA). Further details about the shelter can be obtained from the San Dimas Equipment Development Center, 444 E. Bonita Ave., San Dimas, CA 91773.

COMPARISON PROCEDURES

The new aluminum shelter (referred to here as A2) and an available older unit (A1), having the flared-type louvers, were placed near two already exposed wooden shelters over a fescue-wheatgrass surface about 100 to 120 yards (90 to 110 m) west of the NFFL; see figures 1 and 2. The relative setup, with the two aluminum shelters 15 ft (5 m) apart, is depicted in figure 3. The wooden shelters differ somewhat, even though both were constructed to U.S. Weather Bureau (now National Weather Service) specifications. That of more recent make (referred to here as W2), situated inside a fire-weather station enclosure, has a somewhat less open, more slanted louver design and much narrower space between the floorboards as compared with the older shelter (W1); the latter is about 60 ft (18 m) farther west and has been used during the past 10 years for year-round climatological records.

A1

A2

Figure 1.--Closeup of new model aluminum shelter, A2, and older aluminum shelter, A1, showing difference in louver construction and the unpainted interior of A2.

Figure 2.--View (facing west) of thermometer shelter test location, near Missoula, Montana; two aluminum shelters are at left, two wooden shelters at right.

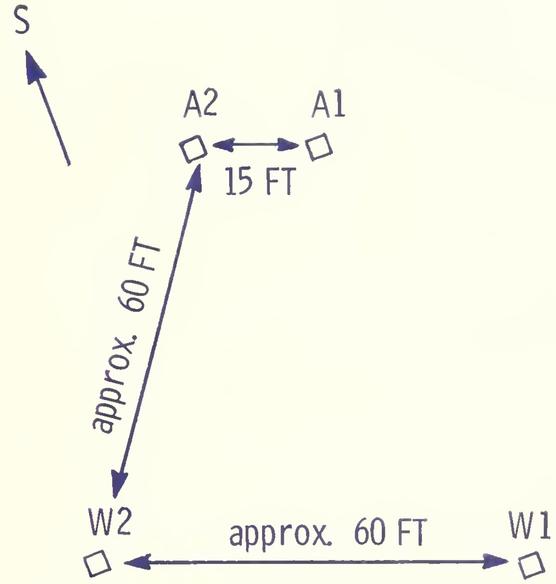

Figure 3.--Relative location of four thermometer shelters in field about 100-120 yards (90-110 m) west of Northern Forest Fire Laboratory. "A" denotes aluminum shelter, "W" wooden ("cotton-region") shelter, "1" older model, "2" newer model.

Comparisons between the shelters are based on the daily extreme temperatures (daytime maximum and overnight minimum) obtained from standard maximum and minimum thermometers. These instruments were read, to the nearest 10th degree Fahrenheit, Monday through Friday (excluding holidays) at about 0900 or 1000 m.s.t., also near 1400 m.s.t. during the fire-weather observation season (May through October). Additional readings were made occasionally on late Friday afternoons or weekends. Approximately 15 to 20 usable comparisons could be made each month. Hygrothermographs provided a reading check but were available only for shelters W1 and W2. They also helped in spotting occasional 24-hour maximums and minimums, mainly in winter, that did not occur during the prescribed daytime and overnight periods. For example, during a warming trend, the minimum actually may have been the temperature at the time when the thermometer was set on the previous morning; the maximum may have occurred around the current morning's observation time. Such readings were not used.

Thermometers were checked against each other and for accuracy by their current readings (and those of a psychrometer dry bulb) during cloudy and breezy conditions; also several times by immersion in stirred water of varying temperatures. Three of the four maximum thermometers had no detectable error; the remaining one, switched between shelters A1 and A2, required a correction of -0.2° to -0.4°F (-0.1° to -0.2°C) at temperatures below 80°F (27°C). All four minimum thermometers had slight, rather constant errors that were not due to any bubble formation in the liquid column; readings were corrected by adding between 0.2° and 0.6°F (0.1° and 0.3°C). An occasional problem was the sliding of the minimum thermometer index pin due to wind vibration of the shelter. This sliding occurred with all shelters except W2 but was mostly alleviated by a near-horizontal setting of the thermometer and firmer bracing of shelter supports. Larger errors from this source were obvious and readings could safely be rejected, but small ones such as 1°F (about 0.6°C) could possibly pass through our data inspection.

Comparisons presented here use shelter W2 as the primary standard; as shown later, this type appears to give most closely the true (outside shelter) air temperature. The comparisons cover the period from July 16, 1976, through January 31, 1978. There is, however, a gap of more than 3 months--October 1976 through mid-January 1977--in those involving A2, due to the temporary return of this shelter to San Dimas Equipment Development Center. Estimates or adjustments could be made for this missing period, using the comparisons between A1 and W2.

RESULTS

The courses of average monthly differences between shelters, together with the extreme daily differences, are plotted in figure 4. A frequency distribution of daily differences is shown in figure 5. Scatter diagrams of daily differences vs. corresponding maximum and minimum temperatures are given in figure 6; this allows some comparison with the figure 2 presented in Forest Service, USDA (1964).

Average and Extreme Differences

Maximum temperature.--As seen in figure 4, monthly average differences of +0.7° to +1.4°F (+0.4° to +0.8°C) occurred during March through September between the maximum temperatures inside shelters A2 and W2; average differences during autumn and winter months were mostly +0.4° to +0.5°F (+0.2° to +0.3°C) or less. There is not, however, a smooth relationship with the monthly average maximum temperature. Extreme daily differences reached about +3.0°F (+1.7°C) in June and July (1977) and also in January (1978). The available monthly differences averaged mostly between 0.6° and 1.1°F (0.3° and 0.6°C) smaller than those between shelters A1 and W2.

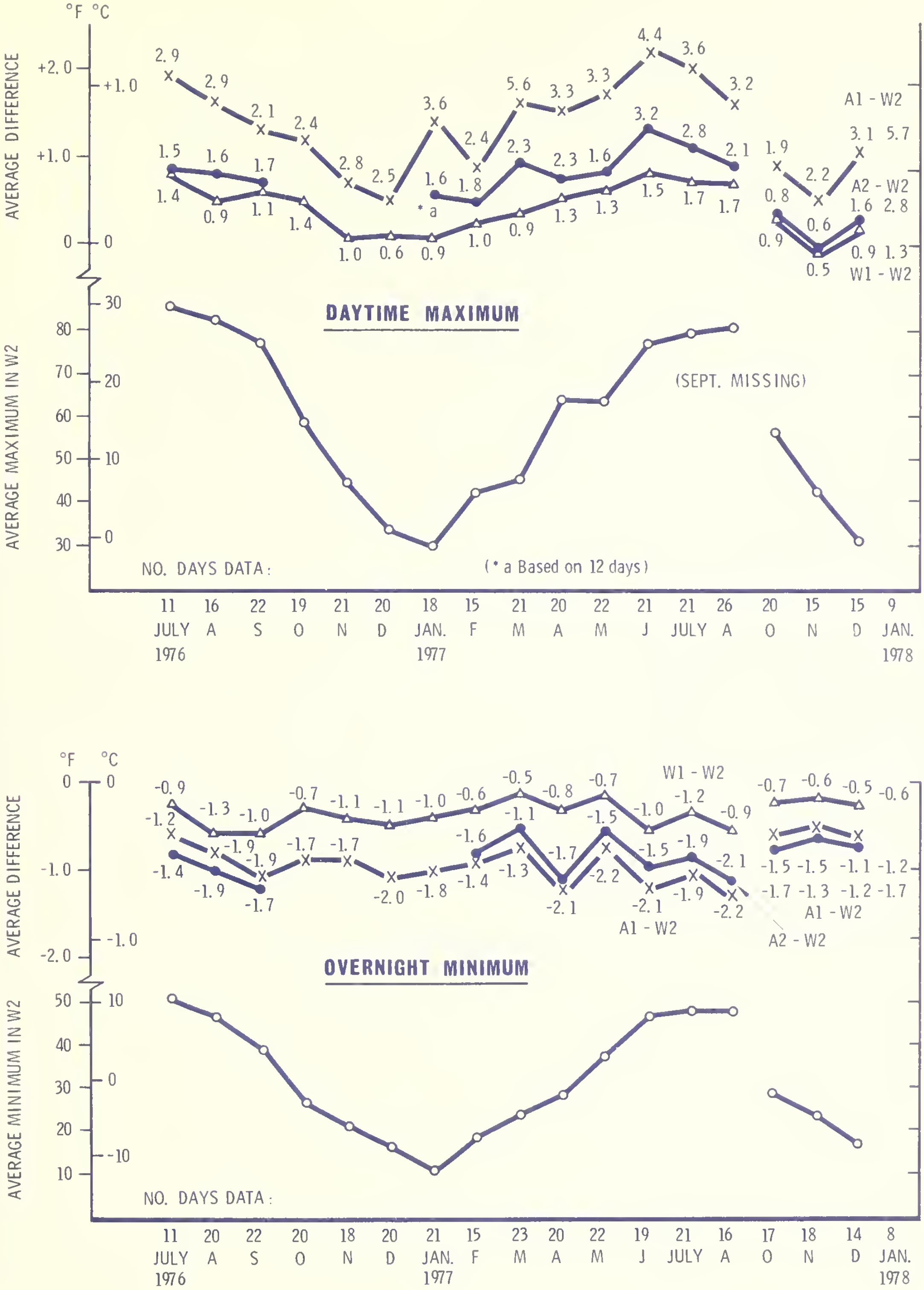

Figure 4.--Average monthly daytime maximum and overnight minimum temperatures inside "cotton-region" shelter (W2) and differences with other shelters (see legend, figure 3). Numbers adjacent to points are extreme differences (°F) during month, July 1976-January 1978 (September 1977 missing). Heavy dot denotes A2-W2; X, A1-W2; triangle, W1-W2.

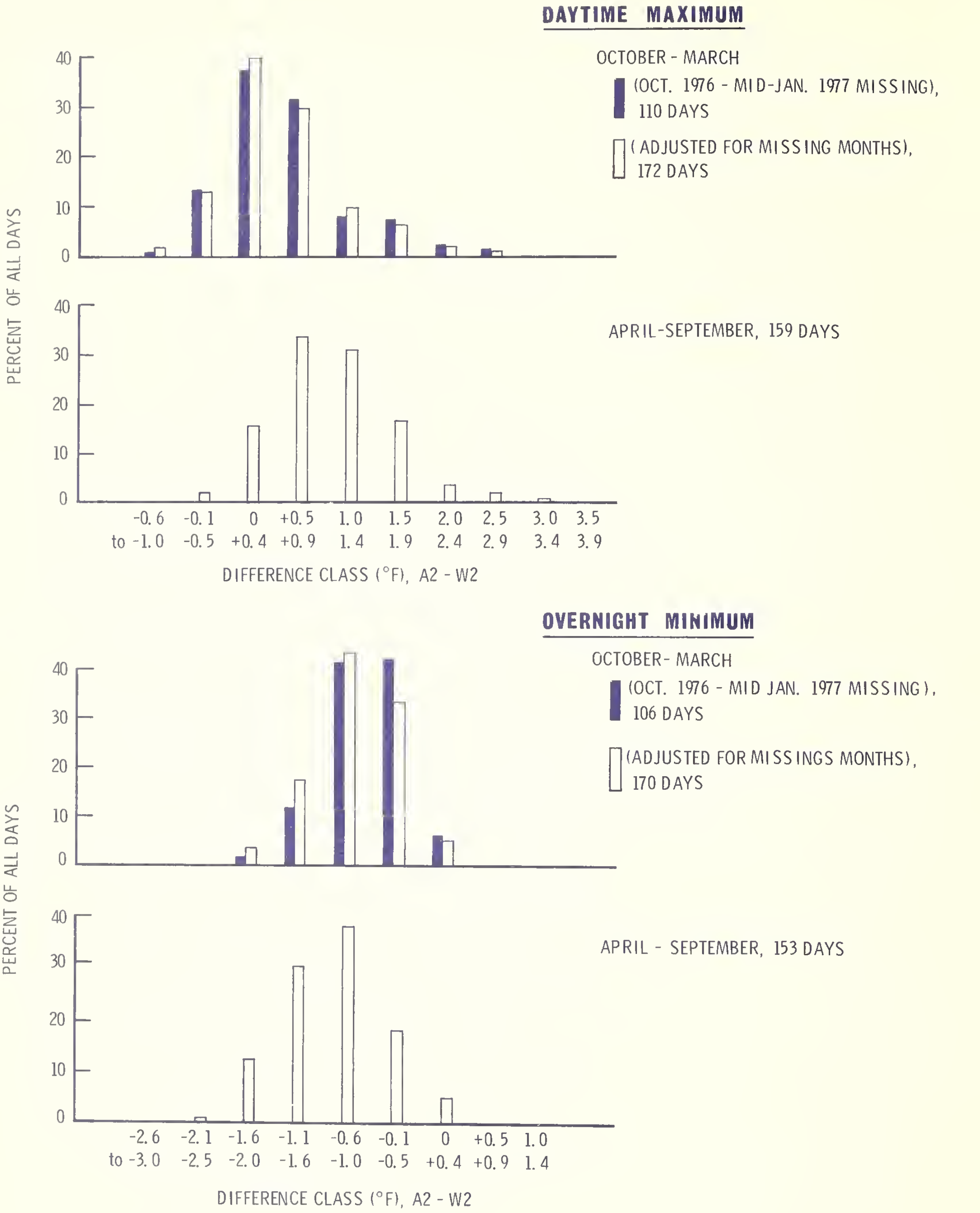

Figure 5.--Percent frequency of daily differences in temperature between shelters A2 and W2, by 6-month periods, October-March and April-September. Upper panel: daytime maximum. Lower panel: overnight minimum. Based on readings during July 1976-January 1978. Adjustment for missing months (October 1976 through mid-January 1977) made with aid of differences between shelters A1 and W2. Differences are given by classes having 0.5°F interval; multiply values by 0.56 for conversion to °C.

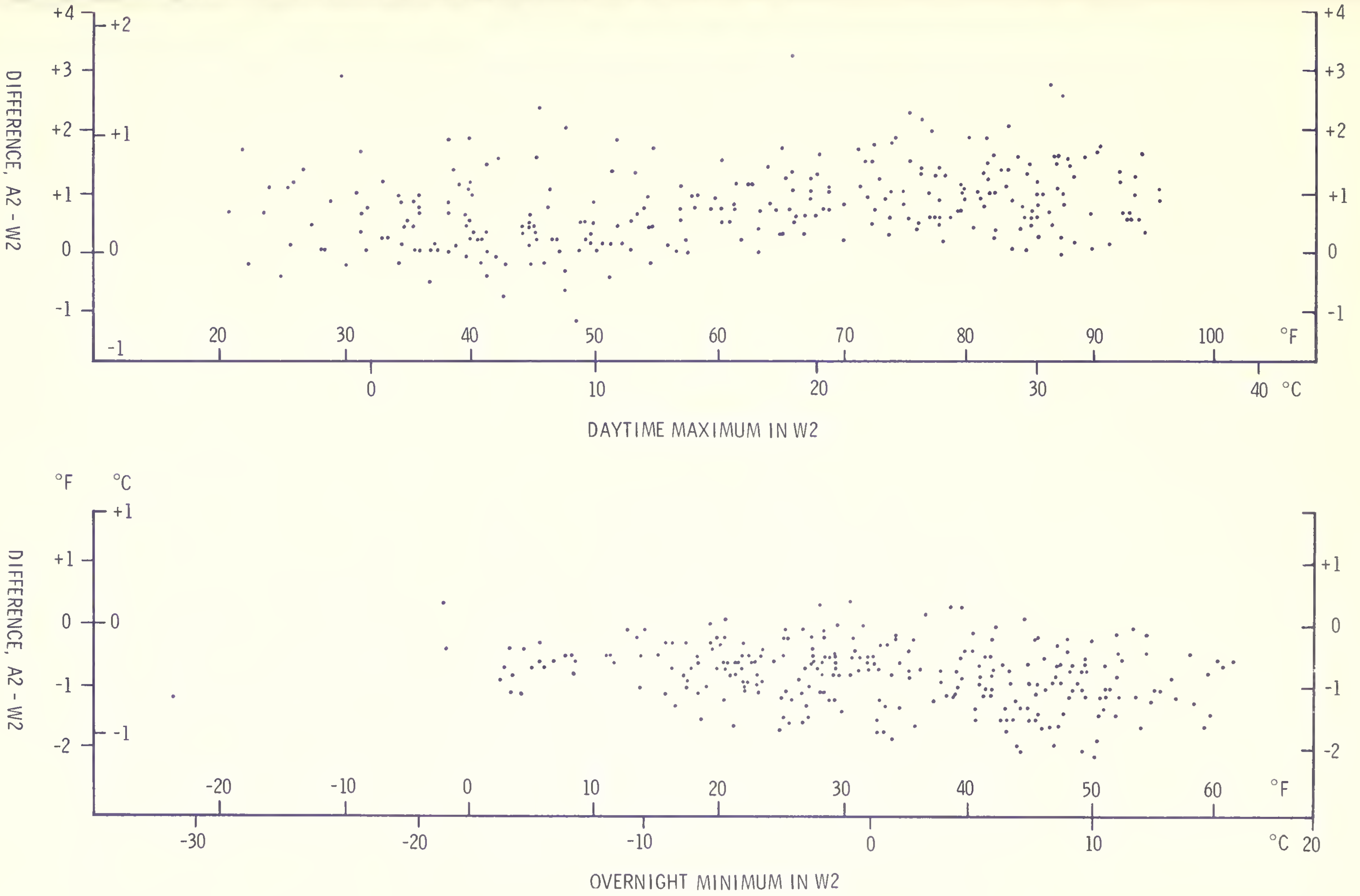

Figure 6.--Differences in daytime maximum and overnight minimum temperatures, shelters A2-W2, vs. maximum and minimum readings in shelter W2. Based on days during July-September 1976 and January 1977-February 1978.

The A1-W2 monthly average differences, reaching close to +2.0°F (+1.1°C) in spring and summer, are basically similar to those shown between the aluminum and wooden shelters in the above (1964) reference; extreme daily differences during 1977 reached +3.6°F (+2.0°C) in January as well as July and peaks of +5.6°F (+3.1°C) in March and +4.4°F (+2.4°C) in June. As described later, A1-W2 differences equaling the March figure were observed during January 1978.

Differences were somewhat smaller with reference to shelter W1, inside which daily maximums were occasionally 1.0° to 1.5°F (0.6° to 0.8°C) higher than those inside W2. Monthly average differences between these wooden shelters ranged from 0° to 0.3°F (0° to 0.2°C) during November-January to 0.8° or 0.9°F (0.4° to 0.5°C) during June-August.

Minimum temperature.--Shelters A2 and A1 appear similar with respect to overnight minimums. Their monthly average values were mostly within ±0.2°F (±0.1°C) of each other or within the range of possible error in correcting the thermometer readings. These average values were between 0.5° and 1.2°F (0.3° and 0.7°C) lower than those of W2; and between 0.2° and 0.9°F (0.1° and 0.5°C) lower than those of W1. Little seasonal regime is found in these differences or in the extremes, which reached around -1.5° to 2.0°F (-0.8° to -1.1°C) during most months.

Frequency Distribution and Dispersion of Differences

Figure 5 separates the data into two 6-month periods, October-March and April-September, based approximately on the equinoxes and average temperature. During the first period, e.g., the most frequent daytime maximum temperature differences between A2 and W2 fall into the 0° to +0.4°F (0° to +0.2°C) and +0.5° to +0.9°F (+0.3° to +0.5°C) classes; these account, respectively, for about 40 and 30 percent of all cases. The distribution for the warmer season shows a slight shift, putting the most frequent differences into the +0.5° to +0.9°F (+0.3° to +0.5°C) and +1.0° to +1.4°F (+0.6° to +0.8°C) classes; these account for 33 and 30 percent of all cases. Differences of +2.0°F (+1.1°C) or greater occurred on but 4 percent of the days, compared with 40 percent for A1-W2.

Figure 6 shows wide scatter in the A2-W2 daily differences as a function of maximum or minimum temperature. As with the monthly average differences in figure 4, there is only a slight trend. At most, a best-fit curve for daytime maximum may slope from about +0.5° or +0.6°F (+0.3°C) at 32° to 50°F (0° to 10°C) to about +1.2°F (+0.7°C) at 80°F (27°C) and higher.

DISCUSSION OF RESULTS

Statistical Significance of Differences

Using shelter W2 as the standard, the daily performance of A2 was evaluated by chi-square accuracy tests (Freese 1960); this was done only for the April-September period, when average differences between these shelters' maximum temperatures tended to be largest. For the tests, the daily thermometer readings were rounded off to the nearest whole degree F, as they are in actual climatological or fire-weather practice. The A2-W2 differences were then obtained in whole degrees--though, on a given day, a 1°F difference could represent an actual difference as small as 0.1°F (0.1°C), e.g., 74.5° minus 74.4°F, or as large as 1.9°F (1.1°C), e.g., 76.4°F minus 74.5°F. The tests were made using first the original A2 data and then the data with the "bias" (the average A2-W2 difference) removed from each A2 observation. As seen earlier, the bias (rounded off) amounts to +1°F (about +0.6°C) for maximum temperature throughout April-September; -1°F for minimum temperature.

Two separate accuracy requirements, strict and more lenient, were specified; these asked, respectively, that each day's data from shelter A2 be within 1° and 2°F of the W2 data at the 95 percent probability level. The chi-square calculations actually used limits of 1.4°F (0.8°C) and 2.4°F (1.3°C). To avoid bias due to possible day-to-day persistence, the tests used data sampled at least 3 days apart.

The test results, based on 70 sample days (as well as all 161 available days), show that the originally observed A2 maximum temperatures meet only the lenient accuracy requirement; the strict requirement is met, however, when 1°F is subtracted from each reading. Similarly, based on 67 sample days (as well as all 153 available days), the A2 minimum temperatures meet the strict requirement only when 1°F is added to the original values.

More favorable results are obtained if the A2 data are tested against those from the older design wooden shelter, W1; many of these shelters continue in use. Relative to this standard, the observed, uncorrected A2 maximum and minimum temperatures both meet the 1°F accuracy requirement; the April-September "biases" are only +0.25°F (0.1°C) and -0.6°F (-0.3°C), respectively.

Aside from the chi-square test results, which relate to the reliability placed in an individual observation, the overall (time-integrated) performance may be of greater interest. From this standpoint, the observed A2-W2 differences in rounded-off maximum temperatures exceeded 1°F on 22 percent of the spring-summer days; they exceeded 2°F on 2 percent. When 1°F is subtracted from each A2 maximum, the differences with W2 exceeded only 1°F on 2 percent of the days; similarly, when 1°F is added to each A2 minimum.

Sources of Differences

The differences in readings between thermometer shelters (assuming that instrumental error is absent or removed) have two possible explanations: differences in errors from radiation (solar and terrestrial) and differences in lag effects (involving rate of response to outside-air temperature changes). These are both related to the shelter materials and design (e.g., louver construction). The lag factor may be dominant when the air temperature is fluctuating rapidly at the time of maximum or minimum. Overall, however, the radiation factor appears to prevail. Dominating radiation errors are found with the standard wooden shelters (e.g., by sling psychrometer comparisons), and thus the above differences must represent greater errors from the aluminum shelters.

A 4-month test reported by the Forest Service, USDA (1964), at a Maryland site shows average maximum temperatures inside a cotton-region shelter between 1.3° and 0.7°F (0.7° and 0.4°C) higher (during August and November, respectively) than those from a force-ventilated "telepsychrometer." Minimum temperatures are between 0.3° and 0.7°F (0.2° and 0.4°C) lower. The shelter in this test may have been of the older W1 design; shelter W2 generally compares favorably with another force-ventilated device, as discussed in the following section.

Radiation Effects

As indicated in figure 6, the deviations of shelter A2, mainly from radiation errors, vary with the individual day and night (and hour). They should be least under cloudy, windy conditions and greatest when there are clear skies and little or no wind. Overall, greatest effects on daytime temperatures might be expected in spring and summer when the sun's rays are most direct and intense. The presence of a highly reflective snow cover can lead to equally large effects on sunny (or bright though cloudy) winter days. Our results indicate, however, that shelter A2 is much less affected than shelter A1 by this condition, which on a late March day brought to A1 its largest error during 1977 (+5.6°F, or 3.1°C); similarly large errors occurred on 2 days in January 1978.

As already shown, the radiation errors of shelter W2 are apparently smaller than those of shelter W1. An idea of the W2 error was sought by comparing its data with those from a "hygrothermometer" (designated here as HT) at the nearby Missoula airport, located about 1.0 mile to the southeast. This electronic device, having a shielded sensor exposed on the field (at a height of 4 ft, or about 1.2 m), has been used by the National Weather Service for the official temperatures at its airport stations since about 1960. Forced ventilation practically eliminated errors from radiation. Its response time, or lag, is adjusted to equal that of the standard liquid-in-glass thermometers. Errors can, however, arise with respect to calibration; a tolerance of ±1°F (about ±0.6°C) is specified. Such errors should, over a space of years, average near zero but will be systematic over durations that can cover a few months or longer before the equipment is adjusted. The standard, once-weekly checking procedure is such that errors of 2°F (1°C) can actually occur for extended durations; at many stations, it involves comparisons with a psychrometer inside a roof-mounted wooden shelter.

Because of differences in local environment, exact agreement between the HT and W2 daily and average temperatures would not be expected even if there were no errors from radiation or the instruments. Nevertheless, a sample of 104 spring and summer days (46 during July-September, 1976, and 58 during May 1-July 24, 1977) yielded an average W2-HT difference of -0.3°F (-0.2°C) in daily maximum temperature (-0.2° and -0.4°F, or -0.1° and -0.2°C, for the two respective periods). Individual daily differences ranged from -2° to +2°F (-1° to +1°C) and were zero on 43 (or 41 percent) of the days. The afternoon radiation error of shelter W2 might thus appear negligible, overall; or at least there is a good balance between opposing effects of radiation and shelter lag. The W2 site does not have the possible pavement effects of the airfield, which may contribute to the slightly higher average temperature from HT (itself situated over a natural surface). In the cooler months, however, the W2-HT differences are usually positive in sign during sunny days with snow on the ground and very light wind, with differences commonly 2°F (1°C) or more.

A sample of 96 overnight minimum temperatures (44 and 52 nights during the above two periods) gave an average W2-HT difference of -0.8°F (-0.4°C), with -0.6° and -0.9°F (-0.3° and -0.5°C) for the respective periods. Individual differences ranged from -4°F (-2°C), on a single occasion, to +2°F (+1°C). Site factors may be responsible for about half of this negative-sign average difference.

Radiation Error and Shelter Design

Finally, we may ask why the various shelters perform differently. Explanations offered here are based mainly on the field results and familiar physical principles, rather than laboratory-type tests.

An ideal thermometer shelter or screen should protect thermometers from direct and indirect radiation (as well as from precipitation) while allowing adequate ventilation. The airflow through the louvers serves both to communicate the ambient air temperature to the thermometers and to remove heat absorbed by the shelter (MacHattie 1965, World Meteorological Organization 1971). From our results, it appears that the open, flared-louver construction of some of the earlier aluminum (A1) units allows entry of reflected solar radiation. Added to this may be terrestrial (outgoing, infrared) radiation emitted from the sunlit ground surfaces. The narrower louver openings and the wire-mesh backing of A2 allow less direct airflow but, overall, this apparently is well balanced by the reduced entry of radiation. The high-gloss white exterior of A2 appears effective against absorption of radiation. The unpainted, gray interior of this shelter should be an advantage over the previous white-painted interior, which would more easily reflect entered radiation to the thermometers.

The large holes in the floor of shelter A1 were suspected as another entry for radiation while contributing little to ventilation. The importance of upward radiation is shown by MacHattie (1965) in shelter experiments in Canada. Such holes are found in A2, but the open area is interrupted somewhat by the wire mesh. To test the above speculation, the floor of A1 was on July 27, 1977, entirely covered by a barrier of 3/4-inch plywood. Maximum-temperature differences through August 18 were then compared with those before this treatment. The average A1-W2 difference, based on 20 days, was found to be +2.0°F (+1.1°C); the average A1-A2 difference, +0.8°F (+0.4°C). These differences are nearly identical to those during the several preceding spring and summer months, as seen in figure 4. Further, comparisons during the following winter showed that this treatment brought no reduction in A1-W1 differences with snow on the ground; e.g., extreme differences of +5.7° and +5.5°F (3.2° and +3.1°C) were observed during January 1978, while corresponding A2-W2 differences were +1.1° and +2.8°F (+0.6° and +1.6°C).

Thus, the improvement of A2 over A1 evidently results from the louvered wall construction and possibly also from differences in paint (or its absence). Paint is apparently not a factor in the improvement of W2 over W1; no change in average temperature differences is evident following identical new coats given to these wooden shelters during early June 1977. Again, the louver design of W2 appears more favorable.

SUMMARY AND CONCLUSIONS

The results of about 15 months' comparison near Missoula, Montana, show that a new model portable aluminum thermometer shelter (referred to here as A2) performs well as a field-use alternative to the standard wooden "cotton-region" shelter empoyed at climatological and fire-weather stations. Differences in afternoon (or at least daily maximum) temperature, attributed mainly to radiation effects, average about one-half those of an earlier aluminum unit (A1). Evaluation was made with reference to a more recent design wooden shelter (W2), which, at least in the absence of a reflecting snow cover, generally gives readings approaching those of the true (outside-shelter) air temperature.

In the Missoula climate, the assumed errors raise the average observed A2 maximums between approximately 0° to 0.5°F (0° to 0.3°C) in cloudy, late autumn and early winter months and upward to 1.0° to 1.4°F (0.6° to 0.8°C) during spring and summer months. These average values depend largely on the number of sunny days and the intensity of the incoming (or reflected) solar radiation. Errors as large as +1.5° to +3.0°F (+0.8° to +1.7°C) do occur on individual days throughout the year. Shelter A1 gave extreme errors of between +5.5° and +5.7°F (+3.1° and +3.2°C) on 3 days (1 in March and 2 in January) under a combination of sunshine, very light wind, and snow cover. Inside A2 the errors on these same days ranged from +1.1° to +2.8°F (+0.6° to +1.6°C); the W2 maximums were themselves somewhat too high.

At night, outgoing radiational cooling of the shelter is the main factor in lowering the average observed A2 minimums below those of W2. The difference, on a monthly basis, averaged between -0.5° and -1.2°F (-0.3° and -0.7°C), with little seasonal regime; this represents little or no improvement over shelter A1. Extreme deviations occasionally reach -1.5° to -2.0°F (-0.8° to -1.1°C); these appear to be influenced in part by differences in shelter lag under conditions of rapidly fluctuating air temperatures.

The accuracy or reliability of the A2 readings on a daily basis, relative to W2, was examined by chi-square tests performed for the warmer portion of the year, when the portable shelter may find its greatest use. These tests indicate that, during spring and summer, subtracting 1°F (about 0.6°C) from the rounded-off observed A2 maximum should result in accuracy within 1°F at the 95 percent probability level; otherwise, accuracy will be within 2°F (about 1.1°C) at this probability level. A similar result occurs with respect to adding 1°F to the rounded-off observed minimum temperature.

The performance of A2 is in closer agreement with that of an earlier design wooden shelter (W1), still serving many stations. In fact, averaged over the year, the observed A2-W1 maximums differed by only +0.2°F (0.1°C); the W1-W2, by +0.5°F (0.3°C). Chi-square tests using W1 as the standard would show the uncorrected A2 daily maximums and minimums both within 1°F accuracy at the 95 percent probability level.

Thus, from a practical standpoint, the temperature (and relative humidity) data obtained from the new aluminum shelter should be adequate without correction. If there is interest in closely comparing average temperatures (e.g., 10-day or monthly) with those from standard reporting stations, the above details indicate the range of corrections that may apply. Possible errors of uncorrected instruments may, however, either add to or reduce those ascribed to radiation.

The favorable results from this point comparison should generally apply for at least the warmer part of year in other portions of the United States. Some variation in exact figures can be expected, related to differences in sunshine and windspeed (and ground surface) factors.

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HEAT CONTENT OF BARK, TWIGS, AND FOLIAGE OF NINE SPECIES OF WESTERN CONIFERS[1]

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and
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ABSTRACT

Comparative combustion tests showed that bark, twigs, and foliage of nine commercial timber species in the Northern Rocky Mountains generally produce more heat than equal volumes of their ovendry wood and that these parts of harvested trees could be profitably utilized as a source of energy.

KEYWORDS: Heat/specific, bark utilization, twigs, foliage, conifers, utilization (wood)

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[1] This Research Note reports results of a cooperative project of the Intermountain Forest and Range Experiment Station and the Wood Chemistry Laboratory, University of Montana, Missoula.

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INTRODUCTION

Ever since the energy crisis of 1973 the United States has been increasingly concerned about the limited supply of certain sources of energy, particularly the fossil fuels. The fact that these fuels are of limited supply necessitates that they be used as efficiently as possible and that industry constantly search for new sources of energy. Today the renewable natural resources, particularly wood, are being examined and evaluated as potential sources of both chemicals and energy. It has been estimated that the United States annually produces 588 X 10^6 tons of dry collectible biomass that has a total energy content of 8.2 X 10^{15} Btu's, or approximately 12 percent of the nation's energy consumption (Reed 1975).

About one-fifth of this unused biomass is produced by America's forest industries, much of it during the harvesting process: small-sized trees, tops, stumps, roots, branches, bark, and foliage (Hakkila 1976). The cost of collecting and delivering these materials to a utilization site has been the major constraint on their use. For decades it has been cheaper to leave this material in the forest as slash to be burned or to decompose.

Since the development of whole-tree harvesting equipment these forest residues now can be processed more economically than previously and use of this material as a source of chemicals and energy is coming closer to realization. In Russia, for example, foliage is being converted to an animal fodder-vitamin supplement called "muka" (Keays 1976). All forest residues can be used to produce methanol which, in turn, can be used as fuel for automobiles or in homes. Near utilization sites these residues can be burned to produce steam and electrical energy.

When forest residues are burned directly to produce energy, the heat of combustion is their prime value. Higher heating values for stemwood and bark of some western conifers have been reported (Chang and Mitchell 1955; Dobie and Wright 1975; Lieu and others 1978; and Susott and others 1975), but virtually no information has been published about the heat value of twigs and foliage of these species. The purpose of the cooperative research project reported here was to provide information about the heat value of these other residues.

PROCEDURE

Samples of bark, twigs, and foliage were collected from the nine principal commercial timber species of the Northern Rocky Mountains. The species sampled were: western redcedar (*Thuja plicata* Donn.), grand fir (*Abies grandis* [Dougl.] Lingl.), western larch (*Larix occidentalis* Nutt.), western white pine (*Pinus monticola* Dougl.), Engelmann spruce (*Picea engelmannii* Parry), lodgepole pine (*Pinus contorta* Dougl.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and ponderosa pine (*Pinus ponderosa* Laws.). About 4 pounds (1.8 kg) of sample material was obtained from harvest residues of several trees of each species. Branches not attached to the stem were classified as twigs. Twenty-seven samples were prepared for analysis.

All samples were air-dried and ground in a mill so that the materials could pass a 60-mesh screen. Prior to analysis all materials were compressed into pellets to aid combustion. Heating values were measured in an automatic adiabatic calorimeter that had been calibrated with pellets of benzoic acid. Values determined from the 1-gram samples were corrected to allow for combustion of the ignition wire, the free acids formed during combustion, and the moisture content of the sample. The moisture content of the ground sample material was calculated using the ovendry weight. Average moisture content for all samples was 9.3 percent. The heating values measured in the combustion tests were converted to megajoules per ovendry kilogram.

A minimum of three replicates was run for each plant material; additional replicates were run whenever the results of three replications showed variation of more than 5 percent. No difficulties were encountered in burning any of the sample materials.

RESULTS

In general, for any one species, bark had the highest heat value, and foliage the lowest. The principal exception was western redcedar, wherein foliage had the highest average heat values and bark had the lowest (table 1).

For bark, the average heating values ranged from the low of 20.16 Mj/kg for western redcedar to a high of 25.23 Mj/kg for Douglas-fir (8,669 to 10,845 Btu's/lb). The average heating value of the bark for all species, including all determinations, was 22.01 Mj/kg or 9,461 Btu's/lb. The range of average values for the twigs was from 20.26 for western redcedar to 23.32 Mj/kg for ponderosa pine (8,708 to 10,026 Btu's/lb). The overall average value for twigs was 21.48 Mj/kg or 9,233 Btu's/lb. For foliage, the average values ranged from 20.24 Mj/kg for western larch to 22.40 Mj/kg for western redcedar. Comparable values in Btu's per pound were 8,703 and 9,630. The overall average for the foliage was 21.67 Mj/kg or 9,315 Btu's/lb.

A comparison of the higher heating values, in Btu's per ovendry pound, showed that, with the exception of western redcedar and the twigs of Douglas-fir, the average higher heating values of the bark, twigs, and foliage exceeded the average heating value of the species' wood. For bark, the heating value was an average of 740 Btu's (1.72 Mj/kg) greater than the wood and for twigs and foliage the averages were 512 and 594 Btu's (1.19 and 1.38 Mj/kg), respectively.

Table 1.--*Average higher heating values (ovendry basis) of wood, bark, twigs, and foliage of the nine principal commercial timber species in the Northern Rocky Mountains*

	Average higher heating value						
	Wood[1]	Bark		Twigs		Foliage	
	Btu/lb	*Mj/kg*	*Btu/lb*	*Mj/kg*	*Btu/lb*	*Mj/kg*	*Btu/lb*
Western redcedar	9,700*	20.16--8[2]	8,669	20.26--5	8,708	22.40--4	9,630
Grand fir	8,300*	22.43--6	9,641	20.69--5	8,894	22.09--7	9,497
Western larch	8,370**	21.31--3	9,162	21.51--3	9,247	20.24--3	8,703
Western white pine	8,620+	21.76--3	9,355	22.07--5	9,464	21.03--3	9,040
Engelmann spruce	8,100*	22.37--3	9,616	21.11--3	9,076	20.48--3	8,806
Lodgepole pine	8,600*	22.34--3	9,605	21.80--5	9,371	21.78--3	9,365
Western hemlock	8,500*	23.13--3	9,943	20.76--3	8,924	22.08--3	9,491
Douglas-fir	9,200*	25.23--3	10,845	21.20--8	9,113	21.55--6	9,265
Ponderosa pine	9,100*	21.99--3	9,452	23.32--6	10,026	22.16--6	9,527
Average	8,721	22.01--35	9,461--35	21.48--43	9,233--43	21.67--38	9,315--38

[1] Sources: *Dobie and Wright; **Susott and others; and + Lieu and others.
[2] The number after the dash is the number of determinations made.

When heating values of the various tree parts were subjected to analysis of variance, both the tree part and the species were found to affect the heat content value. To examine these differences in detail, the t-statistic was used to compare means both within and between species. Table 2 shows the comparisons of tree parts for each species. Only 5 of the 27 comparisons of mean heat contents were not significant at the 5 percent level. Figure 1 graphically compares values for each tree part of all nine species. For bark, 7 of the 36 comparisons were not significant; for twigs, 6 of the 36 comparisons were not significant; and for foliage, 9 of 36 comparisons were not significant. Although the majority of the mean higher heating values is significantly different statistically, these differences would have little practical importance.

Table 2.--*Within-species comparisons of the mean higher heating values of bark, twigs, and foliage for nine Northern Rocky Mountain species*

Species	Comparison of		
	Bark vs. twigs	Bark vs. foliage	Twigs vs. foliage
Western redcedar	-	+	+
Grand fir	+	-	+
Western larch	+	+	+
Western white pine	-	+	+
Engelmann spruce	+	+	+
Lodgepole pine	+	+	-
Western hemlock	+	+	+
Douglas-fir	+	+	-
Ponderosa pine	+	+	+

Note: Plus (+) and minus (-) signs indicate statistically significant and nonsignificant differences between means at the 5 percent level.

BARK

SPECIES	WRC	GF	WL	WWP	ES	LP	WH	DF	PP
Western redcedar	▨	+	+	+	+	+	+	+	+
Grand fir	▨	▨	-	-	-	-	-	+	-
Western larch	▨	▨	▨	+	+	+	+	+	+
Western white pine	▨	▨	▨	▨	+	+	+	+	+
Engelmann spruce	▨	▨	▨	▨	▨	-	+	+	+
Lodgepole pine	▨	▨	▨	▨	▨	▨	+	+	+
Western hemlock	▨	▨	▨	▨	▨	▨	▨	+	+
Douglas-fir	▨	▨	▨	▨	▨	▨	▨	▨	+
Ponderosa pine	▨	▨	▨	▨	▨	▨	▨	▨	▨

TWIGS

SPECIES	WRC	GF	WL	WWP	ES	LP	WH	DF	PP
Western redcedar	▨	+	+	+	+	+	+	+	+
Grand fir	▨	▨	+	+	+	+	-	+	+
Western larch	▨	▨	▨	-	+	-	+	-	+
Western white pine	▨	▨	▨	▨	+	-	+	+	+
Engelmann spruce	▨	▨	▨	▨	▨	+	+	-	+
Lodgepole pine	▨	▨	▨	▨	▨	▨	+	+	+
Western hemlock	▨	▨	▨	▨	▨	▨	▨	+	+
Douglas-fir	▨	▨	▨	▨	▨	▨	▨	▨	+
Ponderosa pine	▨	▨	▨	▨	▨	▨	▨	▨	▨

FOLIAGE

SPECIES	WRC	GF	WL	WWP	ES	LP	WH	DF	PP
Western redcedar	▨	-	+	+	+	+	-	+	-
Grand fir	▨	▨	+	+	+	-	-	+	-
Western larch	▨	▨	▨	+	+	+	+	+	+
Western white pine	▨	▨	▨	▨	+	+	+	+	+
Engelmann spruce	▨	▨	▨	▨	▨	+	+	+	+
Lodgepole pine	▨	▨	▨	▨	▨	▨	+	-	+
Western hemlock	▨	▨	▨	▨	▨	▨	▨	-	-
Douglas-fir	▨	▨	▨	▨	▨	▨	▨	▨	+
Ponderosa pine	▨	▨	▨	▨	▨	▨	▨	▨	▨

[1] Plus (+) and minus (-) signs indicate significant and nonsignificant differences between means at the 5 percent level.

Figure 1.--*Between species comparisons*[1] *of the mean higher heating values of bark, twigs, and foliage for nine Northern Rocky Mountain tree species.*

The higher heating values produced by the bark samples are similar to those reported for the same species by Dobie and Wright (1975), and the values for foliage are comparable to those reported by Hough (1969) for conifers in the southern and eastern United States.

CONCLUSIONS

The higher heating values for bark, twigs, and foliage indicate that these materials have essentially the same heat content as the wood of the same species--possibly more; therefore these materials should be equally suitable or even preferred as sources of energy. Statistical comparisons indicated that mean higher heating values both within and between species were significantly different at the 5 percent level, but it is doubtful whether these differences would have practical importance in industrial use.

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Research Note

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SEEDLING WATER RELATIONS OF TWO GRASS SPECIES ON HIGH-ELEVATION ACID MINE SPOILS

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ABSTRACT

Revegetation is the most successful long-term solution to the problems caused by surface mining. However, the characteristics of mine spoils that limit natural colonization by plants often require amelioration before successful plant establishment can be achieved. High elevation disturbances in the western U.S. are particularly severe because geologic materials are often of pyritic origin resulting in lethal pH levels, poor waterholding characteristics, and toxic concentrations of heavy metals. Superimposed on these limiting site characteristics are constraints of short, cool, growing seasons and the possibility of diurnal frost action. These conditions severely limit the number of adapted vascular plant species suited for revegetation. Research was conducted at 2 925 m elevation on the McLaren Mine, near Cooke City, Montana, to determine the effects of some spoil-ameliorating treatments on water relations and growth of Poa alpina *and* Alopecurus pratensis *seedlings. Organic matter incorporated in the spoil material together with a surface mulch reduced seedling mortality and resulted in larger plants. The effects of those treatments on plant responses under controlled conditions in a growth chamber are also discussed.*

KEYWORDS: revegetation, mine rehabilitation, Beartooth Plateau, Montana, water stress, soil amendments, grass seedlings.

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Many problems are associated with surface mine disturbances in the mountainous terrain. One of the most obvious problems is the complete destruction of both the native vegetation and the edaphic environment. In addition, various off-site concerns can develop, including damage to vegetation, deterioration of water quality, and loss of wildlife and aquatic habitats. Erosion and stream sediment loads lead to decreased water quality (Striffler 1973). Acid-water runoff from mines containing high concentrations of heavy metals can be lethal to aquatic organisms and to downslope vegetation and that along streambanks (Johnston and others 1975; Warner 1973).

The most successful long-term solution to these problems appears to be revegetation of the spoils. However, many constraints limit the success of revegetation, either by natural colonization or by artificial means. Exposed parent materials are low in essential nutrients for plant growth, and the coarse spoil texture and lack of organic matter contribute to low cation-exchange capacities. Acid is produced by the oxidation of sulfides in pyritic spoils, and the resulting low pH restricts both nutrient availability to and water absorption by plants. Toxic levels of heavy metals such as copper, iron, and aluminum can prevent plant growth and establishment (Antonovics and others 1971).

Bare spoils have a larger daily temperature fluctuation than vegetated areas (Schramm 1966). The coarse texture of the spoils and the low levels of organic matter also contribute to low water-holding capacity and to rapid drying rates. Plants must be adapted to the short growing seasons, high solar radiation loads, heavy winds, and frequent disturbances caused by congeliturbation (the turning or heaving of the soil by freezing and thawing) at high elevations. Only a relatively few vascular plant species are adapted to these conditions (Brown and others 1978; Billings 1974).

Conditions on surface mines must be improved if mined areas are to be revegetated. Other studies have demonstrated that fertilizers are essential in many areas (Brown and others 1976; Dunbar and Adams 1972; Johnston and others 1975; Vogel and Berg 1973). Applications of lime have improved plant yields on acid soils (Chadwick 1973; Dunbar 1974) and mulches have been used to improve spoil water status (Gregg 1976). Unfertilized plots established at the McLaren Mine in 1974 had a lower plant density than fertilized plots (Brown and Johnston 1976). Many seedlings on the unfertilized plots were desiccated, an indication that water stress is a severe problem in the establishment of seedlings at high elevations.

OBJECTIVES AND HYPOTHESES

The first objective of this study was to determine the extent to which soil amendments and surface mulches lessen seedling water stress on high elevation (subalpine-alpine ecotone) mine spoils. Both a field study and a growth chamber study were conducted to determine the effects of four treatments on leaf water potential. These studies tested the hypothesis that seedlings on spoils treated with an organic matter amendment and a surface mulch will be subjected to less water stress than seedlings on untreated spoils.

The second objective was to determine the influence treatments had on seedling mortality. The hypothesis tested was that seedling mortality will be lower on spoil materials treated with an organic matter amendment and a surface mulch than on untreated spoils.

STUDY SITE DESCRIPTION

The field study was conducted through the 1976 growing season on the McLaren Mine (109°59' W, 45°04' N) at 2 925 m (9,600 ft) elevation near Cooke City, Montana, on the southern edge of the Beartooth Plateau. This area contains highly mineralized geologic strata that occur on the flanks of the main uplift of the Beartooth Plateau. The Cooke City ore body, which is a portion of this uplift, is a hydrothermal pyritized copper deposit (Loverling 1929). The primary minerals of economic value that were mined include gold, silver, and copper. The Cooke City area has a history of mining dating back to the 1880's (Glidden 1976). Although the McLaren Mine was operated at intervals as a shallow open pit mine until it was abandoned in the early 1950's, there is still some mineral exploration at the mine site today.

Environmental conditions at the study site are characterized by short growing seasons of 60 to 70 days, low summer temperatures, and relatively high solar radiation (Johnston and others 1975). Annual precipitation, most of which occurs during the winter (September to July), is estimated to range between 1 100 and 1 500 mm (43 to 59 in) (Johnston and others 1975). Localized summer storms cause precipitation to vary between sites in close proximity. Johnson and Billings (1962) described the plant communities of undisturbed alpine areas on the Beartooth Plateau.

METHODS

Field Study

At the McLaren Mine, snowmelt generally is not complete until August 1. Seeded plots, each 0.5 m^2 (19.7 by 39.4 in), were established on a nearly level portion of an abandoned roadbed on the mine July 6 and 7, 1976 (fig. 1). The physical and chemical characteristics of the spoils at the site (table 1) are representative of the majority of overburden materials on the mine (Brown and others 1976). Nonacid snowmelt streams near the site were used as a supplemental water supply.

A completely randomized block design with four blocks of eight plots was used (fig. 1). Two plant species, *Poa alpina* L. (Alpine bluegrass), a native, and *Alopecurus pratensis* L. 'Garrison' (meadow foxtail), a commercially available species, were seeded. *Poa* seed was collected on the Beartooth Plateau in 1974; *Alopecurus* seed was obtained from a commercial source in early 1976. The four spoil treatments were: (1) a control group with no treatment, (2) peat moss incorporated into the spoils, (3) a surface mulch of jute netting, and (4) peat moss plus jute netting.

We removed snow and large rocks from the site and loosened the soil with hand-tools to a depth of 10 cm (4 in). Soil pH was measured with a portable meter at several locations on the site, and, using a volumetric 1:1 mixture of soil and distilled water, we found that the pH ranged between 2.8 and 3.0. Hydrated lime was applied uniformly at the rate of 0.12 kg (0.26 lbs) per plot to raise the pH to 6.5.

Individual plots, 0.5 by 1.0 m (19.7 by 39.4 in), were staked and treatments were applied according to the completely randomized block design. All plots received an 18:46:10 N:P:K granular fertilizer at an equivalent rate of 111 kg of nitrogen per hectare (100 lbs per acre). Peat moss was applied to the selected plots at 10 percent by volume (5 000 g or 11 lbs per plot). Lime, fertilizer, and peat moss were all incorporated in the soil to a depth of 10 cm (4 in). All treatments were based on recommendations made by Brown and Johnston (1976).

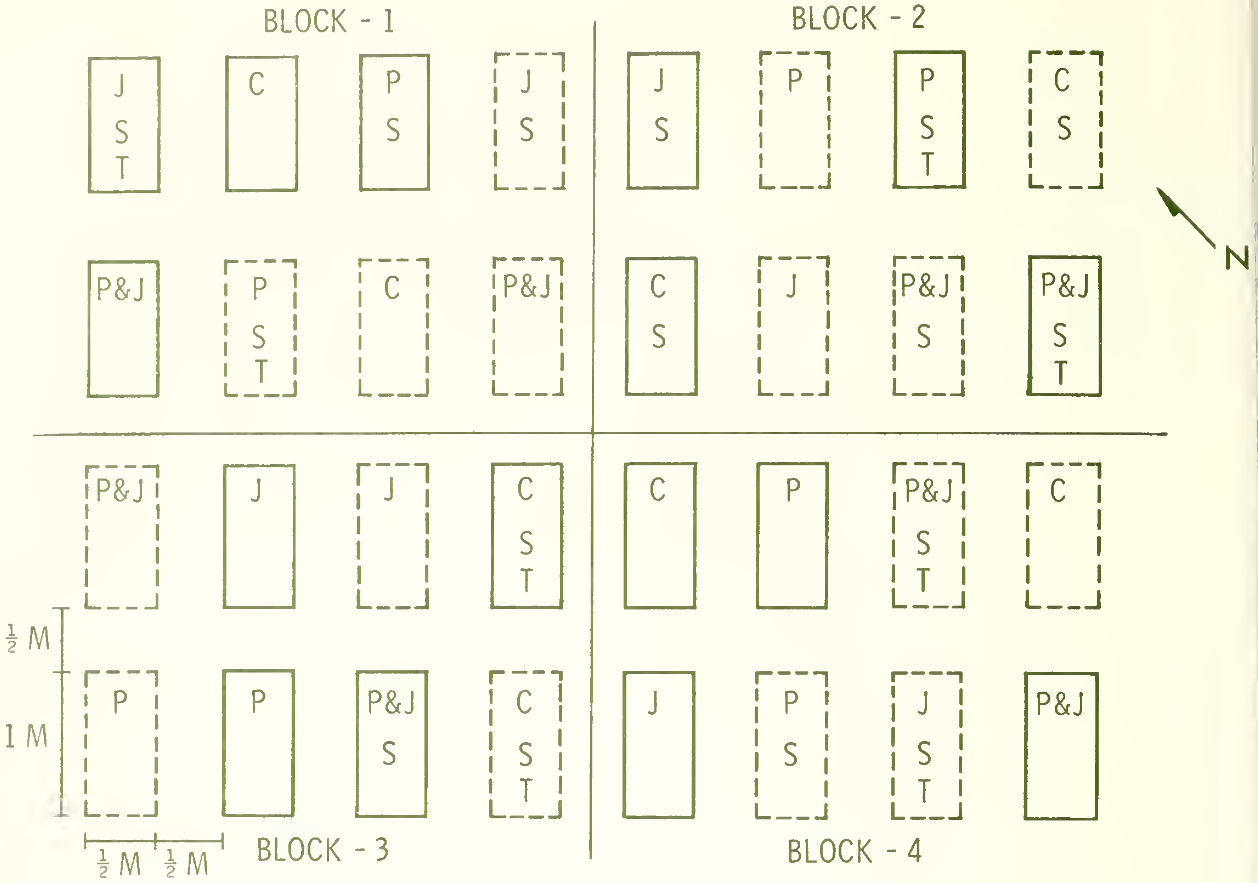

Figure 1.--Plot layout for the seedling water relations study at the McLaren Mine. Plot size is 0.5 x 1.0 m. The following symbols are used: *Alopecurus pratensis* = ———— ; *Poa alpina* = — — — ; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J; Soil water potential measurements = S; Tensiometer measurements = T.

Table 1.--*Analyses of spoils collected on the McLaren Mine at the end of the field season, September 1976*

Sample location	pH	EC_e[1]	Estimated texture	Percent coarse fragments	NH4OAC Extract K	Ca	Mg	Percent P total	Available phosphorus	SO_4
					- - *meq/100 g* - -				*p/m*	*meq/liter*
Roadbed	1.7	9.4	Clay loam	72	0.1	1.4	3.3	0.05	6.7	523
Seedling plot	1.7	13.4	Clay loam	73	.09	3.4	3.0	.04	7.2	414

Sample location	Fe	Soil analysis (DPTA) Zn	Mn	Cu	H2O soluble Al	Cu	NO_3-N	Cation exchange capacity	Saturation percent	Percent N
	- - - - - - -	- - - -	- - -	*p/m*	- - - -	- - - -	- - - -	*meq/1,000 g*		
Roadbed	1250	7.4	10.8	26.5	390	53.3	0.3	13.3	32.7	0.02
Seedling plot	916	5.2	12.0	27.9	430	59.0	.1	13.3	32.8	.02

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[1] Electrical conductivity, mmhos/cm.

Seeding rate was established from laboratory germination results and previously observed emergence rates at the McLaren Mine (Brown and others 1976). Germination of *Alopecurus* and *Poa* seeds on filter paper was 60 and 27 percent, respectively. On the basis of previous observations, it was expected that only 25 percent of the seedlings germinating in the laboratory would emerge in the field. To produce 1,200 seedlings per plot, 5.0 g (0.01 lb) of *Alopecurus* seeds (1,600 seeds per g) or 5.1 g (0.01 lb) of *Poa* seeds (3,300 seeds per g) were used. Seeds were broadcast uniformly over the surface, raked into the soil to a depth of 1 cm (0.3 in), and packed. Jute netting was laid over the appropriate plots and anchored outside the plot boundaries with rocks. Approximately 27 cm (10.6 in) of snow was reshoveled onto the plots to simulate natural conditions. Since there was little precipitation in July 1976, plots were sprinkled daily with snowmelt water until plants reached the second leaf stage.

Sampling began on August 9, when plants reached the second leaf stage. Leaf water potential was estimated from leaf samples collected daily between 1400 and 1600 hours, the time of maximum water stress. Several seedlings from each plot were sealed in a thermocouple psychrometer equilibration chamber and then placed in an insulated reservoir where water temperature was kept at approximately 25° C. The samples were allowed to equilibrate for 2 hours before readings were taken.

Seeding development, plant density, and seedling mortality were determined within a 10 by 40 cm (4 by 16 in) subplot centered within each plot. Measurements of leaf water potential were not taken from the subplots because such measurements required destructive sampling. At weekly intervals, the numbers of live plants, dead plants, and leaves and the range of plant heights within the subplots were recorded.

All psychrometers used in this study were Peltier double-junction thermocouple psychrometers (Van Havern and Brown 1972). Psychrometers were attached to stainless steel Swagelok-brand[2] tube fittings to form small watertight equilibration chambers. Psychrometer output was measured with an SB-600 psychrometer readout meter.

Growth Chamber Study

McLaren Mine spoils were sieved to 2 mm (0.078 in) and then lime and fertilizer were added at the same rates used in the field study. Peat moss was added to half the spoils also at the rate used in the field study. The mixtures were then placed in 1 liter plastic pots with no drainage holes. The seeding rate needed to produce 100 seedlings per pot was calculated to be 0.1 g of *Poa* or *Alopecurus* seeds. The seeds were covered with 0.5 cm (0.2 in) of sieved spoils. A single layer of jute netting was applied to the appropriate pots. There were four replications of each species-treatment combination.

In the greenhouse, the pots received a 14-hour photoperiod by extending the day length with supplemental fluorescent and incandescent lighting in the evenings. Pots were irrigated with deionized water and kept in a nonstressed condition until seedlings reached the second leaf stage. At this stage of growth, the plants were placed in a Sherer-Gillett CL-37-14 growth chamber. Plants were allowed to equilibrate to growth chamber conditions for 48 hours before sampling started. The growth chamber was programed for a 14-hour light period at 27° C and a 10-hour dark period at 21 ° C. Relative humidities for the light period ranged from 25 to 35 percent and for the dark period from 43 to 68 percent.

[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.

A drying cycle was initiated after the 48-hour equilibrated period by withholding water from the plants. Daily leaf water potential was measured using the same technique described in the field study methods. A 10-cm^2 (1.55-in^2) in the center of each plot was reserved for measurments of seedlings at the beginning and end of the drying cycle. Measurements taken were similar to those described in the field study methods.

RESULTS

Field Study

Mean leaf water potentials of both species for both the entire field season and for periods of more than 2 days without precipitation were lower (drier) on control (untreated) plots (table 2). Leaf water potentials of plants grown on plots with jute netting or peat moss-plus-jute netting amendments had the highest (wettest) means. The *Poa* control group had the lowest mean leaf water potential, -19.6 bars. Analysis of variance was not conducted on the means because of the wide differences in sample sizes.

Table 2.--*Mean leaf water potentials of field study data for each species-treatment combination. The number of replicates for each mean varies from 22 to 91*

Species	Treatment	Variable	All season	More than 2 days without precipitation
			- - - - - - - - - *Bars*	- - - - - - - - -
Alopecurus pratensis	Control	Mean	-15.3	-22.7
		Std. error	.8	2.8
		± std. error	-14.5 to -16.1	-19.9 to -25.5
Alopecurus pratensis	Peat moss	Mean	-13.3	-16.0
		Std. error	.7	2.6
		± std. error	-12.6 to -14.0	-14.4 to -18.6
Alopecurus pratensis	Jute netting	Mean	-12.2	-19.8
		Std. error	.7	3.0
		± std. error	-11.5 to -12.9	-16.8 to -22.8
Alopecurus pratensis	Peat moss + jute netting	Mean	-11.0	-13.3
		Std. error	.7	2.8
		± std. error	-10.3 to -11.7	-10.5 to -16.1
Poa alpina	Control	Mean	-19.6	-25.4
		Std. error	1.5	2.8
		± std. error	-18.1 to -21.1	-22.6 to -28.2
Poa alpina	Peat moss	Mean	-15.6	-22.7
		Std. error	1.0	2.1
		± std. error	-14.6 to -16.6	-24.8 to -20.6
Poa alpina	Jute netting	Mean	-11.3	-14.5
		Std. error	1.0	4.9
		± std. error	-10.3 to -12.3	-9.6 to -19.4
Poa alpina	Peat moss + jute netting	Mean	-11.5	-18.7
		Std. error	.6	2.9
		± std. error	-10.9 to -12.1	-15.8 to -21.6

The mean daily leaf water potentials over the course of the season are presented in figures 2 and 3. The standard errors indicate the large value range of measured leaf water potential. On any day, there was usually a difference in mean leaf water potential between the control group and the peat moss-plus-jute netting treatment. The variability in the data seemed to increase from August 31 to September 6 when no precipitation occurred. Often during this period, there were not enough *Poa* seedlings to sample on the control plots.

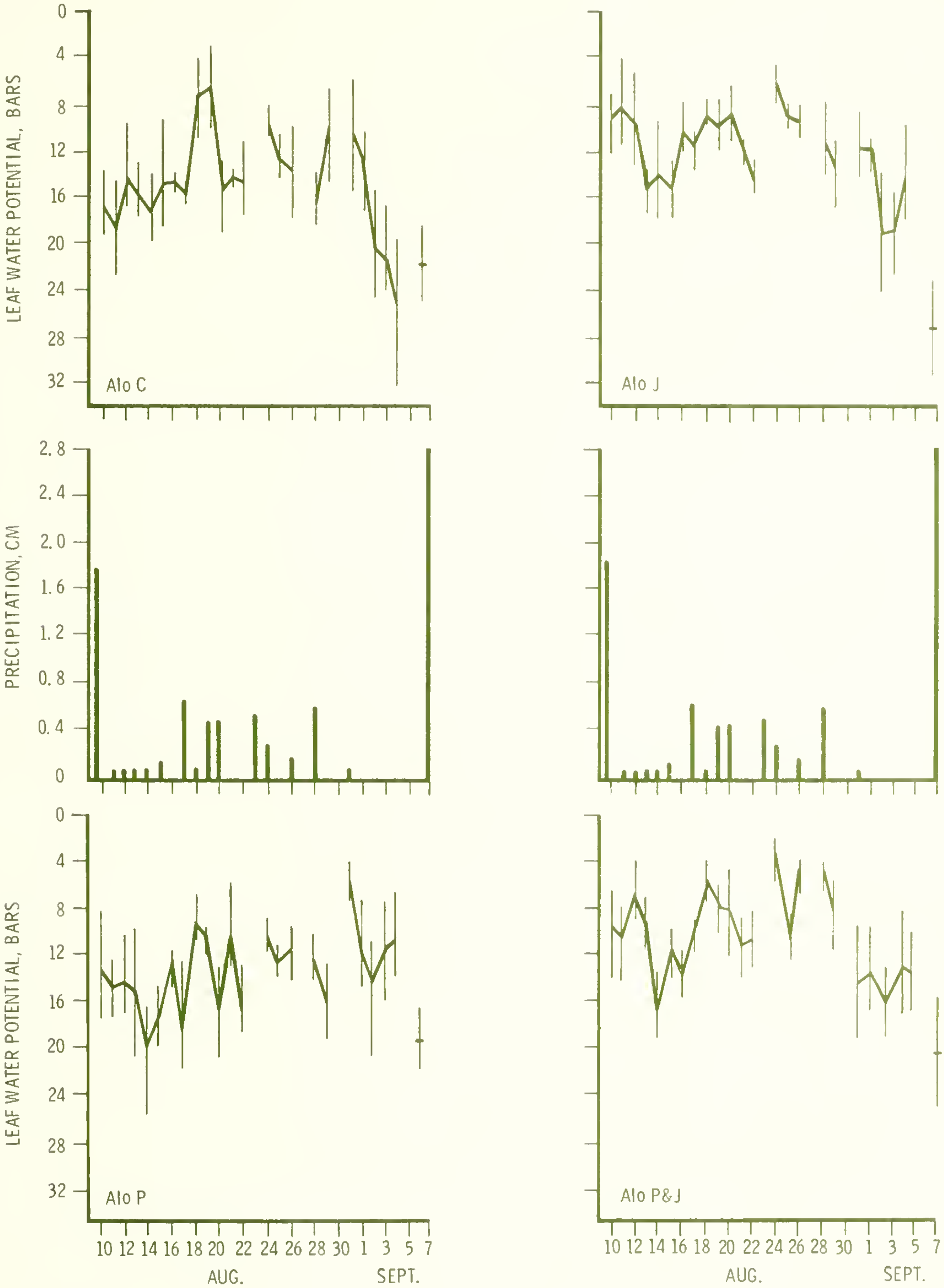

Figure 2.--Mean daily field leaf water potentials with associated standard errors for *Alopecurcus pratensis* and the precipitation record for the field season. The number of replicates for each mean varies from 1 to 4. The following abbreviations are used: *Alopecurcus pratensis* = Alo; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

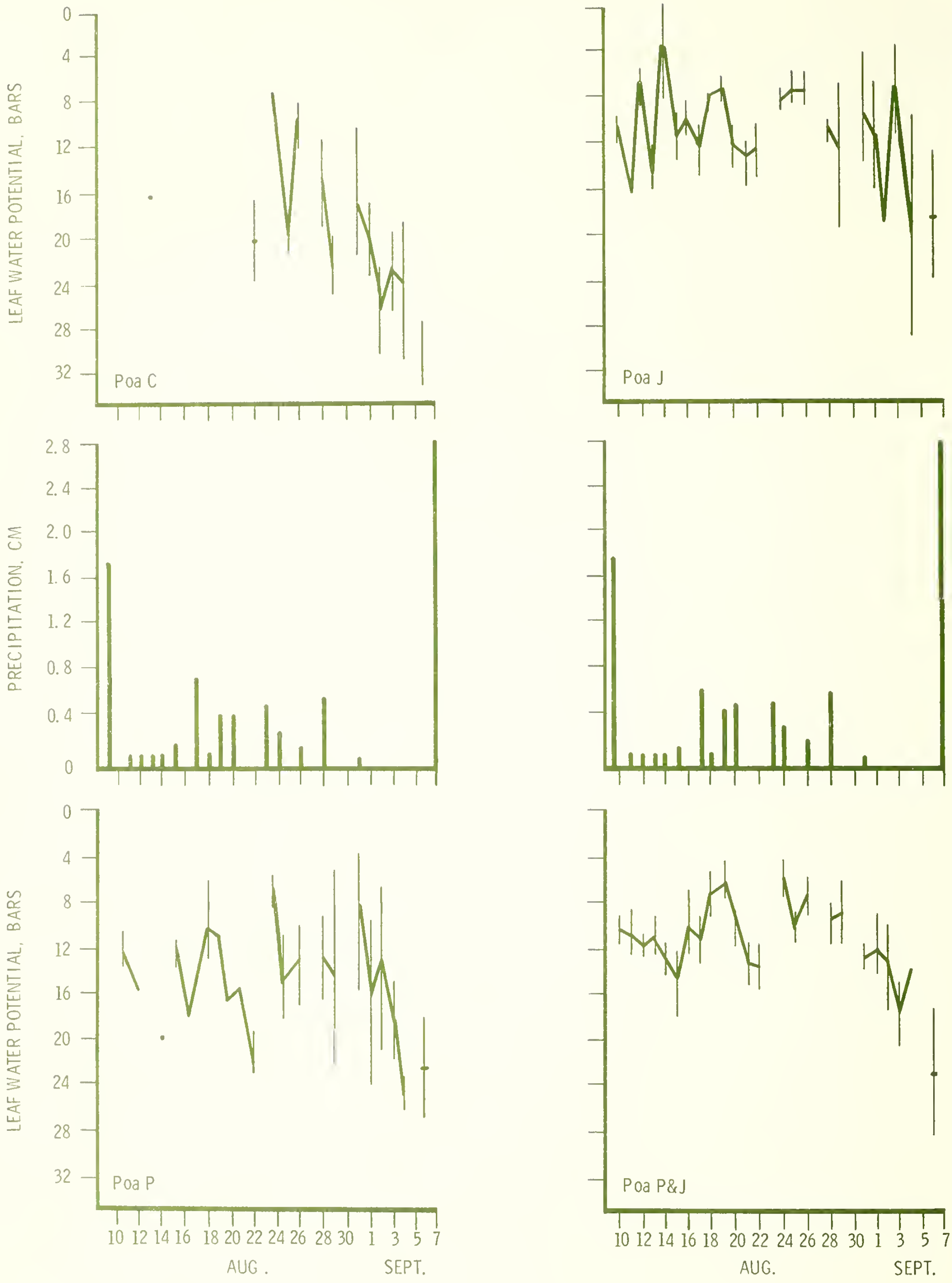

Figure 3.--Mean daily field leaf water potentials with associated standard errors for *Poa alpina* and the precipitation record for the field season. The number of replicate for each mean varies from 1 to 4. The following abbreviations are used: *Poa alpina* = Poa; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

Measurements of seedling mortality and growth on August 30, 1976, are presented in table 3. Analysis of variance of means for each species-treatment combination did not indicate significant difference between replications. There were significant differences between treatments for number of living plants and for species-treatment interactions. *Poa* demonstrates a response to treatments more clearly than *Alopecurus*. According to the seeding rate calculations, there should have been 96 seedlings on each subplot. However, *Alopecurus* consistently had more than 96 plants on each subplot, regardless of treatment. Fewer than 96 *Poa* seedlings per subplot survived except on plots treated with jute netting or peat moss plus jute netting. *Alopecurus* experienced significantly higher mortality than *Poa* and had more leaves and greater minimum and maximum plant heights.

Table 3.--*Mean mortality and growth of seedlings from field plots, August 30, 1976. Abbreviations are:* Alopecurus pratensis = *Alo;* Poa alpina = *Poa; Control groups = C; Peat moss = P; Jute netting = J; Peat moss + jute netting = P & J*

	Group	Number of live plants per subplot	Number of dead plants**	Percent mortality	Minimum plant height**		Maximum plant height**		Most common number of leaves**
					cm	*Inches*	*cm*	*Inches*	
Species	Poa	136.2	8.3	5	0.8	0.31	1.2	0.47	2.2
	Alo	176.4	38.3	18	1.3	.51	2.5	.98	2.9
Treatments	C	110.6*	20.3	16	1.0	.39	1.7	.67	2.4
	P	111.5*	25.4	19	.9	.35	1.5	.59	2.4
	J	185.5*	14.6	7	1.2	.47	2.0	.78	2.9
	P + J	217.0*	19.9	8	1.1	.43	2.1	.83	2.6
Species-treatment interactions	Poa C	47.5*	5.3*	10	.6	.23	1.0	.39	1.8
	Poa P	65.3*	8.3*	11	.8	.31	1.0	.39	2.0
	Poa J	153.5*	14.5*	9	.9	.35	1.3	.51	2.8
	Poa P + J	278.5*	5.0	2	.8	.31	1.4	.55	2.3
	Alo C	173.8*	35.3*	17	1.4	.55	2.4	.94	3.0
	Alo P	157.8*	42.5*	21	1.1	.43	2.1	.83	2.8
	Alo J	217.5*	14.8*	6	1.6	.63	2.8	1.10	3.0
	Alo P + J	156.8*	34.8*	18	1.4	.55	2.8	1.10	3.0

**Significant at the 1 percent level.
*Significant at the 10 percent level.
[1] Subplots were 10 by 40 cm.

Growth Chamber Study

As in the field study, mean leaf water potentials were lower (drier) for control group plants and highest (wettest) for plants with jute netting or peat moss plus jute netting (table 4). However, unlike the field results, the *Alopecurus* control group in the growth chamber had the lowest mean leaf water potential.

Mean daily leaf water potentials during the drying cycle are shown in figures 4 and 5. Usually there were daily differences in mean leaf water potentials between the control group and the peat moss-plus-jute netting treatment. Variability in the data seemed to increase as the drying cycle progressed. Generally, leaf water potentials were drier in the growth chamber than in the field.

There were no significant differences in number of living plants or number of dead plants on the subplots at the end of the drying cycle. There were significant differences between species in number of leaves per plant and in minimum and maximum heights of plants with the most common number of leaves (table 5). *Alopecurus* plants had more leaves and were taller than *Poa* plants.

Table 4.--*Mean leaf water potentials of growth chamber study data for each species-treatment combination. The number of replicates for each mean varies from 14 to 17*

Species	Treatment	Variable	All data	More than 2 days without precipitation
			- - - - - - - - - - *Bars*	- - - - - - - - - -
Alopecurus pratensis	Control	Mean	-20.6	-25.1
		Std. error	2.9	3.9
		± std. error	-17.7 to -23.7	-21.2 to -29.0
Alopecurus pratensis	Peat moss	Mean	-18.5	-21.9
		Std. error	2.1	2.8
		± std. error	-16.4 to -20.6	-19.1 to -24.7
Alopecurus pratensis	Jute netting	Mean	-13.7	-16.3
		Std. error	2.6	5.0
		± std. error	-11.1 to -16.3	-11.3 to -21.3
Alopecurus pratensis	Peat moss + jute netting	Mean	-14.1	-19.3
		Std. error	2.2	2.7
		± std. error	-11.9 to -16.3	-16.7 to -22.0
Poa alpina	Control	Mean	-18.5	-21.3
		Std. error	1.7	2.2
		± std. error	-16.8 to -20.2	-19.1 to -23.5
Poa alpina	Peat moss	Mean	-16.1	-21.0
		Std. error	2.7	3.5
		± std. error	-13.4 to -18.7	-17.5 to -24.5
Poa alpina	Jute netting	Mean	-12.5	-14.3
		Std. error	1.9	2.7
		± std. error	-10.6 to -14.4	-11.6 to -17.0
Poa alpina	Peat moss + jute netting	Mean	-13.8	-15.0
		Std. error	1.7	2.0
		± std. error	-11.1 to -15.5	-13.0 to -17.0

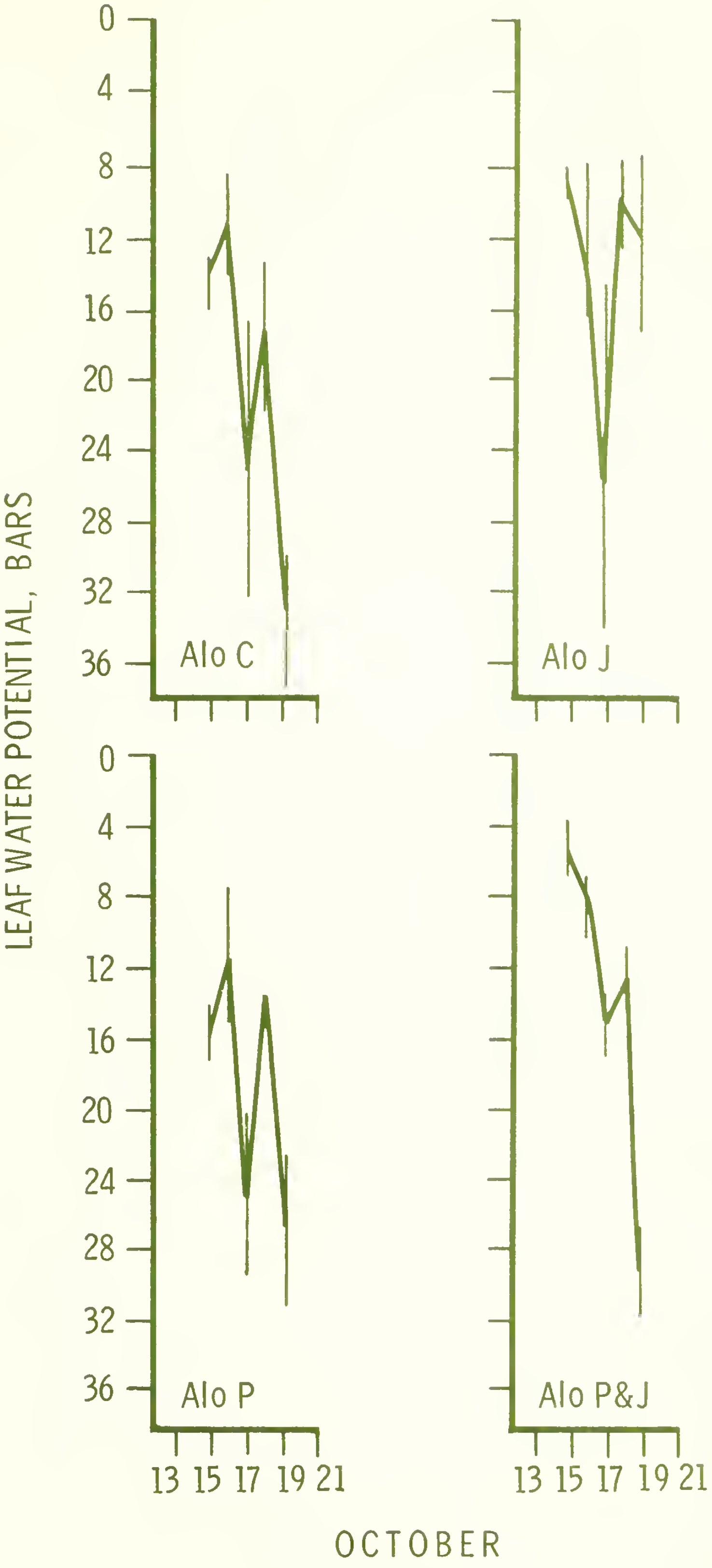

Figure 4.--Mean daily growth chamber water potentials with associated standard errors for *Alopecurus pratensis* during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreviations are used: *Alopecurus prantensis* = Alo; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P & J.

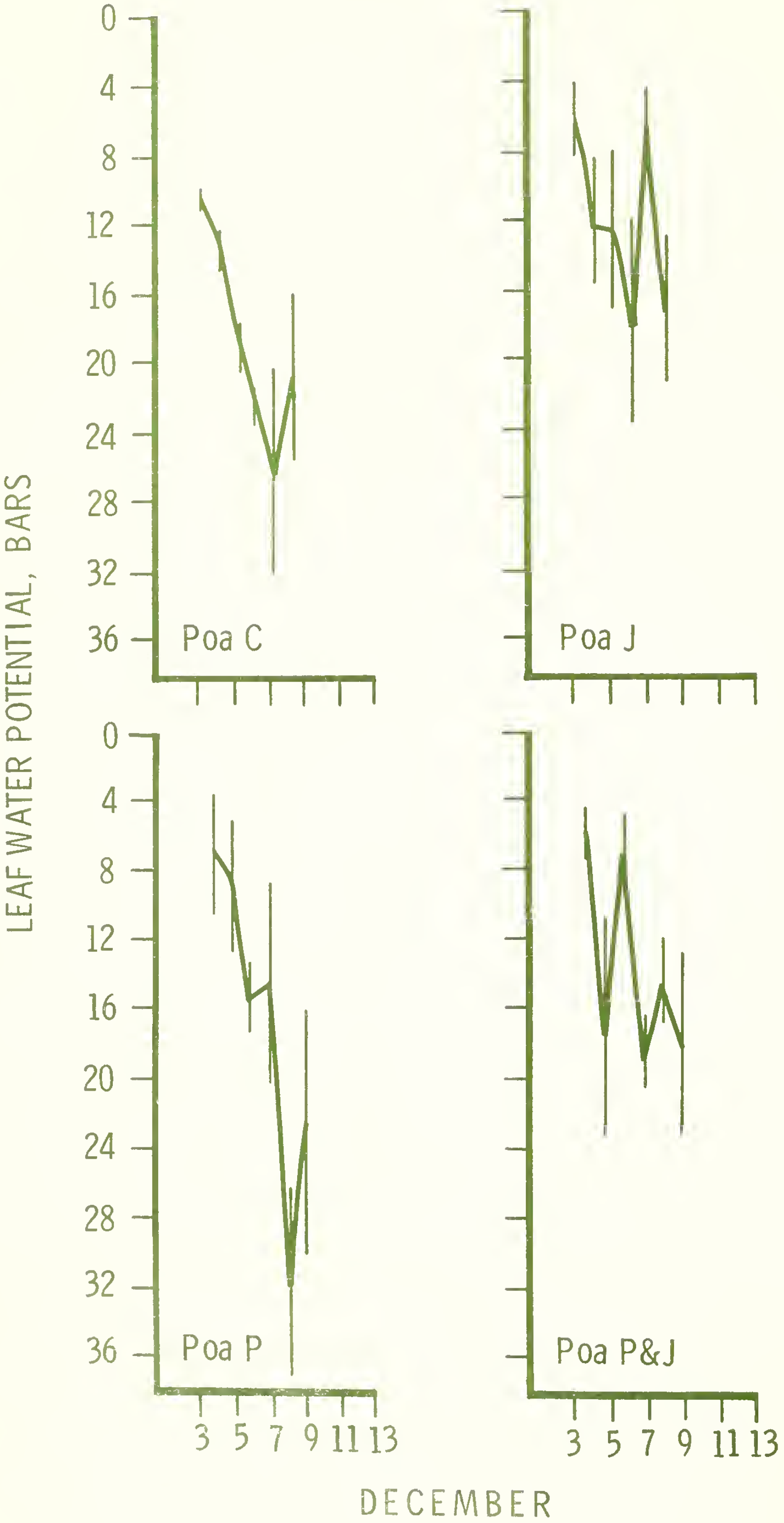

Figure 5.--Mean daily growth chamber water potentials with associated standard errors for *Poa alpina* during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreaviations are used: *Poa alpina* = Poa; Control = C; Peat moss = P; Jute netting = J; Peat moss-plus-jute netting = P &J.

Table 5.--*Mean mortality and growth of seedlings in the growth chamber at the end of the drying cycle. Abbreviations are as follows:* Alopecurus pratensis = *Alo;* Poa alpina = *Poa; Control group = C; Peat moss = P; Jute net = J; Peat moss + jute net = P + J*

	Group	Number of live plants	Number of dead plants	Dead/ live + dead	Minimum plant height**		Maximum plant height**		Most common number of leaves
					cm	*Inches*	*cm*	*Inches*	
Species	Poa	9.3	3.8	0.29	1.2	0.47	2.0	0.78	1.9
	Alo	5.4	1.5	.21	3.9	1.53	6.3	2.48	2.4
Treatment	C	6.1	3.8	.38	1.8	.71	2.9	1.14	1.9
	P	6.0	1.0	.14	1.9	.75	2.8	1.10	2.0
	J	7.6	2.8	.27	3.3	1.29	5.4	2.13	2.4
	P + J	9.6	3.4	.26	3.4	1.34	5.7	2.24	2.5
Species-treatment interactions	Poa C	8.5	5.5	.39	1.3	.51	2.1	.83	2.0
	Poa P	5.8	1.3	.18	1.1	.43	1.3	.51	2.0
	Poa J	9.5	3.5	.27	1.1	.43	2.0	.78	1.8
	Poa P + J	13.3	4.8	.26	1.6	.63	2.9	1.14	2.0
	Alo C	3.8	1.3	.25	2.6	1.02	3.8	1.49	1.8
	Alo P	6.3	.8	.11	2.8	1.10	4.3	1.69	2.0
	Alo J	5.8	2.0	.26	5.5	2.16	8.8	3.46	3.0
	Alo P + J	6.0	2.0	.25	5.3	2.08	8.5	3.34	3.0

**Significant at the 1 percent level.

DISCUSSION

The leaf water potentials measured in 1976 may not reflect the true levels of water stress that plants could experience on the McLaren Mine because the 1976 field season was considerably wetter than the previous year. Approximately 9.7 cm (3.8 in) of precipitation was recorded from August 1 to mid-September 1976, compared to 1.1 cm (0.43 in) of precipitation for the same period in 1975. Spring snowmelt in 1976 began approximately 2 weeks earlier than it had the previous 3 years (1972-1975). However, despite the early snowmelt, frequent rainfall throughout the field season maintained a relatively high soil water content. In a year with less precipitation, soil water potentials probably would be lower. The analyses of predicted leaf water potentials do give an indication of the general effects of the treatments. The lower mean leaf water potential for the *Alopecurus* control group in the growth chamber could be attributed to larger plant size. Both peat moss and jute netting appear to maintain spoil water potentials at higher levels than untreated spoils.

Jute netting appears to be more effective than peat moss in reducing the levels of plant water stress. This could be caused by several microclimatic changes brought about by a jute netting surface mulch. For example, surface mulches lessen the effects of raindrop impact and allow more water to penetrate into the soil (Rickert 1974). The jute netting is a rough barrier to airflow and it creates a larger boundary-layer (pocket) of still air that reduces the rate of evaporation from the soil (Hanks 1967). Also, it may increase the air temperature of the seedling environment. The jute itself absorbs water and evaporation from the fiber provides a higher relative humidity for the seedlings, decreasing the daily depth of soil water loss (Hanks and Woodruff 1958).

The variability in the data collected may be due in part to the genetic variation within the seedling population. The genetic variability is probably high while selective forces are acting upon unadapted organisms in the seedling population (Saraukh and Harper 1973; Canfield 1957). Another source of variability in the data could be plant response to microsite differences (Harper and others 1965).

In the field, there was a high degree of variability in numbers of plants within a species-treatment combination. Some of this variability could be explained by small differences in technique during plot establishment. The spoils are also quite variable and a higher percentage of acid-producing iron pyrite could limit plant emergence. Wind could also cause some variability, which at this location generally blows from the west. Plots treated with peat moss on the west side of the study site had fewer plants than other plots. Also, mortality rates were highest among the relatively few plants on these plots.

The higher mortality of *Alopecurus* plants (table 3) might have been caused by a lower threshold to toxic concentrations of aluminum, zinc, copper, or iron or perhaps by greater competition between plants since *Alopecurus* plants were so large. Although *Alopecurus* has been used successfully in revegetation efforts at high elevation sites in the West (Brown and others 1976; Hendzel 1976; U.S. Forest Service 1966), *Poa* is native to the study area and probably is better adapted to the climatic conditions. *Poa* could be expected to have higher survival than introduced species, such as *Alopecurus*, in these environments.

The number of leaves and heights of plants seemed to be characteristics of species and treatment had little effect. These traits are probably genetically determined.

The plant in the greenhouse and growth chamber were grown in a different environment than that to which the plants in the field were acclimated. Air and soil temperatures were higher and plants grew taller and more quickly than those grown in the field. Larger plant size and more favorable growing conditions may help to explain why there were no significant differences between treatments in the number of living plants or the number of dead plants. As reflected by larger physical size, the plants apparently were responding more to the favorable growing conditions in the growth chamber than they were to the spoil treatments. This was indicated by the larger shoots and perhaps roots of the two species under all treatments studied. Therefore, mortality under these growing conditions may not have been due to treatment conditions, but rather due to genetic variability within the population of seeds used. Total mortality, however, was much higher in the growth chamber than in the field, an indication that plants experienced more water stress during a drying cycle in the growth chamber. Apparently, periods of severe water deficit were longer and more intense from day to day in the growth chamber than in the field.

Tensiometer measurments in the field, indicated that soil water was available at a depth of 7.5 cm (2.95 in). However, plant roots may not have reached this source of water because of acidity, low spoil temperatures, and lack of plant nutrients.

Seedling water stress was reduced by the spoil treatments; treatments of jute netting or peat moss-plus-jute netting were most effective in reducing plant water stress. Treatments of jute netting or peat moss-plus-jute netting decreased rates of seedling mortality in the field, but not in the growth chamber studies.

The results of this study suggest that native species are better adapted for revegetation than are introduced species, at least for the environmental conditions on the McLaren Mine. Care must be taken to select treatments that will ameliorate spoil conditions within the physiological limitations of the plant species being used. In the case of the McLaren Mine, those treatments include: incorporation of lime, fertilizer, and organic matter into the spoil; and a surface mulch to reduce evaporation and the incidence of frost.

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FOREST SERVICE
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A Forest Service
earch Note INT-263

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FIRE - DECAY:
INTERACTIVE ROLES REGULATING WOOD ACCUMULATION AND SOIL DEVELOPMENT IN THE NORTHERN ROCKY MOUNTAINS

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

ABSTRACT

Decay and fire play interactive roles in recycling wood and other organic materials in forest ecosystems, and contribute to the development of high quality soils in the Northern Rocky Mountains. Decayed wood, charcoal, and other decomposed organic matter are the principal media for ectomycorrhizal and nonsymbiotic nitrogen fixing microbes. The activities of these microbes are critical to the growth of forest trees. The balance between decay and fire, as it affects the amount, distribution, and type of organic matter, controls the ability of forest soils to support the growth of trees.

KEYWORDS: Prescribed fire, residues management, fuel management, soil organic reserves, nitrogen fixation, ectomycorrhizal, wildfire.

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The importance of organic materials to the quality of forest soils is frequently obscured by requirements for mineral seed beds to support seed germination and early survival of most conifers. The fire-evolved nature of most Northern Rocky Mountain forests implies that organic materials (fuels) may be expendable. However, in most cases, even after intense wildfires, substantial quantities of large woody fuels remain This wood directly influences soils on these sites. The organic component of soil development, including accumulation of adequate quantities of both decayed and decaying wood plus other organic debris, provide the principal substrata for several important soil functions. Inadequate woody material may cause a regenerating stand to grow more slowly than otherwise possible.

QUANTITY OF WOOD IN FOREST SOILS

The persistance of wood in forest soils has been recognized only recently. Estimates on the quantity of decayed wood in soils vary but in all cases volumes are substa tial. Day and Duffy (1963) estimated that decaying wood made up 16.5 percent of the surface area of one stand in the Rocky Mountains of Canada. McFee and Stone (1966) measured the volume of decayed wood on several forest plots in the Adirondack region of New York State. They reported from 14 to 30 percent of the surface area of these stands was made up of decayed wood. Measurements from western Montana show 15 percent of the top 15 inches (38 cm) of soil consisted of brown, cubical, decayed wood (Harvey and others 1976).

FUNCTION OF WOOD IN FOREST SOILS

The processes and organisms that decay wood are essential to soil development. Th directly influence carbon and mineral cycling. Preliminary measurments indicate that decayed wood has a higher cation exchange capacity than any other component in several of the rocky soils of western Montana. Wood represents a potentially important site for retention of plant nutrients.

Nonsymbiotic nitrogen fixers are dependent on soil organic matter. Data from western Montana show that humus and decayed wood are the principal sites of nitrogen fixing activity, particularly on dry sites (Larsen and others 1978; Harvey and others 1978b; Jurgensen and others 1977). Nitrogen fixing activities have also been reported in decaying wood in the southeast (Cornby and Waide 1973), the northeast (Bormann and others 1977) and the northwestern United States (Aho and others 1974).

Nonsymbiotic nitrogen fixation is critical to forest ecosystems in the Northern Rocky Mountains. In the Rocky Mountain region symbiotic nitrogen fixing plants are frequently less common than in many other regions. Their presence is restricted to early stand development or limited by habitat requirements.

In mature forest ecosystems of the Northern Rocky Mountains, upwards of 90 percent of the active ectomycorrhizal roots of a forest stand are supported by soil organic matter (Harvey and others 1976). During dry periods or on dry sites most of this activity was supported by decayed wood (Harvey and others 1978a, 1978b). Ectomycorrhiz activity in decayed soil wood has also been observed in western Canada (McMinn 1963), the northwestern (Zak 1971; Trappe 1965) and northeastern United States (McFee and Stone 1966).

Wood in forest soils, therefore, contributes to soil quality and stand growth in a broad geographical area.

DECAY-FIRE INTERACTION

The incorporation of wood into forest soils involves a choice or a combination of ological (decay) and physical (fire) forces. Decay is rapid in warm-wet ecosystems ere fire occurs infrequently. Conversely, decay proceeds slowly in cold or dry osystems where fire occurs more frequently.

Decayed wood consists primarily of complex lignin molecules highly resistant to rther biological breakdown. Therefore, highly decayed soil wood should accumulate en on warm-moist sites despite rapidity of decay. On dry or cold sites decay is paired. These sites should accumulate relatively undecayed woody debris until the currence of a wildfire. Fuel accumulation leads to hot wildfires that remove even rge fuels. This will likely deplete the soil wood leading only to accumulations of il charcoal. Sites with intermediate conditions of temperature and moisture should ovide a balanced relationship between these forces.

Preliminary field data indicate that these types of relationships do hold, at ast for selected areas, in the Northern Rocky Mountains.

MANAGEMENT OF WOOD IN FOREST SOILS

Evidence that soil organic reserves, particularly wood, play important roles in intaining forest site quality emphasizes the need to properly manage woody materials. us, the viewpoint that woody residue represents only waste or a fire hazard must be assessed. Forest users and managers must recognize the benefits, equivalent to ng-term fertilization, that woody and other organic reserves contribute to forest osystems.

Although the precise quantities and types of organic materials required to maintain timum site conditions are still under study, some general guidelines for wood manage- nt can be set forth.

Within the Northern Rocky Mountains, the high productivity and rapid decay rates warm-moist forests make them less sensitive to depletion than sites with low-to- derate productivity. However, managing old-growth forests more characteristic of e coastal Douglas-fir region may require conservation of decayed wood, even on oductive sites (Franklin and others 1979). Conversely, management of dry or cold tes should emphasize conservation of large woody materials where this does not eate unacceptable wildfire risk. Such woody materials should, where possible, be ft in contact with the soil to create optimum conditions for decay.

Where early creation of mineral soil seedbeds is critical to reforestation, post- rvest slash treatments should be directed toward a mosaic of fuel dispersal. It ll be advantageous to have both large woody residues and bare mineral surface scattered ross the site so seeds can germinate rapidly and the seedlings can have access, thin a short distance, to the nutrients, moisture, and ectomycorrhizal activity ovided in decaying wood and humus. Size of both slash piles and windrows for pre- ribed burning should be dictated by minimum standards that will achieve adequate duction of small fuel. Soil disturbance should be minimal and not create continuous panses of mineral surface.

Management of wood on intermediate sites is less clear. Until more data are ailable, such sites should be treated as if at least moderately sensitive to reduction soil wood.

An awareness of the importance of wood and other organic reserves to forest eco- stems and the risk of site degradation through wood depletion will help to improve rest practices over wide geographic areas.

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Research Note

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RESISTANCE OF DOUGLAS-FIR TO WESTERN SPRUCE BUDWORM: RESULTS OF A PRELIMINARY PROGENY TEST

Geral I. McDonald[1]

ABSTRACT

Second- and third-instar larvae of Choristoneura occidentalis *placed on 3-month-old* Pseudotsuga menziesii *var.* glauca *seedlings from seven different stands dispersed over all test seedlings and exhibited a feeding preference. Reduced feeding relative to the test mean was observed on progeny from a stand that has survived a long-term and severe budworm outbreak. Within-family patterns of variation were much like those observed for other traits of inland Douglas-fir. Larval dispersion appeared to be greatly influenced by expression of highly developed territorial behavior that included territorial display by larvae established on feeding sites and a common response by the intruding larvae.*

KEYWORDS: Douglas-fir, western spruce budworm, insect resistance of conifers, insect territorial behavior.

A characteristic feature of severe budworm epidemics in Canadian spruce-fir forests is selective mortality. Typically, mortality is lower in white spruce (*Picea glauca* [Moench] Voss) than it is in balsam fir (*Abies balsamea* [L.] Mill.) (Ghent et al. 1957), but little data are readily available on the actual percentage of mature stems per acre surviving. In one case, 20 percent of the merchantable balsam fir

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survived 7 years of intense defoliation by budworm (Blais 1958). In another case, mortality typical of merchantable balsam fir, was said to be 97 percent (Blais 1954). Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [(Bessn.] Franco) growing in the Northern Rocky Mountain area of Montana also exhibited differential survivability (Johnson and Denton 1975). Thus, one can say with confidence that both eastern spruce budworm (*Choristoneura fumiferana* [(Clem] Freeman) and western spruce budworm (*C. occidentalis* Freeman) fails to kill all members of its available and preferred host population during severe epidemics. This phenotypic difference could be due to chance variation associated with tree condition and location or it could be due to genetic variation for resistance. Much evidence exists indicating that genetic interaction can coevolve between insects and their food hosts (Price 1977, van Emden 1973, Gilbert and Rowen 1975). So it is reasonable to hypothesize that budworm was involved in the selective mortality. Since "one must suppose that any agent that selectively destroys genotypes, populations, or whole species as effectively as epidemic disease surely has played a role in the evolution of modern faunae and florae" (Harlan 1976), a reasonable conclusion is that budworm and Douglas-fir could have coevolved a genetic interaction; furthermore, if they have, the selective destruction is generally a two-way affair where the prolonged tug-of-war escalates defenses of both sides, many times, and results in a highly complex coevolved genetic interaction that must be maintained to prevent drastic reduction of fitness (Price 1977). The presence of inherited resistance in the budworm:Douglas-fir system would signal the existence of a coevolutionary interaction and then all the principles applying to such systems would apply to the budworm:Douglas-fir system as well.

The presence of a coevolved system means that if Douglas-fir is to be managed in areas where budworm is a potential problem, an integrated control program that is based on an understanding of the genetic interaction is essential to manage spruce budworm. And budworm appears to be a potential, if not current, problem over most of the range of Douglas-fir (Stehr 1967). Much evidence generated in the development of integrated control strategies for pests (including insects) of agricultural crops shows that an element of prime importance is the genetic interaction of the host population and the pest population (Tummola and Haynes 1977, Kogan 1975). Thus, a basic piece of information needed for the development of a budworm control strategy is the role genetic interaction plays in the relationship between the budworm and Douglas-fir.

The purpose of this paper is to report results from a preliminary progeny test of Douglas-fir seedlings exposed to budworm feeding during their first growing season. The experiment was designed to provide a preliminary test of the following hypothesis: If phenotypic differences in defoliation of Douglas-fir by western spruce budworm are due in part to a coevolved genetic interaction, then open-pollinated progeny obtained from various stands and trees within stands should have a significant amount of variation due to stands or maternal trees.

MATERIALS AND METHODS

Wind-pollinated seeds were collected from several Douglas-fir trees, growing in each of 23 stands in 1969 (Rehfeldt, in press). In early 1978, seed remained for six or seven trees from each of seven stands. These seeds were stratified and then planted in standard pine cells in March 1978. The stand locations and descriptions are given in table 1. On June 6, 1978, several hundred second- and third-instar larvae were collected from the lower portion of the Little Joe drainage near St. Regis, Montana. Larvae were collected by removal of branch tips of Douglas-fir containing entrenched larvae. Branch tips were placed in plastic bags and then transported back to Moscow, Idaho, in ice chests containing ice. The materials were left on ice overnight and larvae were distributed to the 3-month-old Douglas-fir seedlings (average height = 57.8 mm) on the morning of June 7.

Table 1.--*Location and budworm damage status of Douglas-fir stands at time of seed collection in 1969*

Stand	Location	Budworm levels
1	Priest River Experimental Forest, Idaho	No obvious damage
2	Meadow Creek, Nezperce National Forest, Idaho	No obvious damage
3	Idaho Creek, Flathead National Forest, Mont.	No obvious damage
4	Lost Horse Creek, Hamilton, Mont.	Light damage
8	Nez Perce Creek, southwest Hamilton, Mont.	Heavy damage, many trees with crowns gone, current epidemic
20	Honeymoon Creek, Thompson Falls, Mont.	No obvious damage
23	Cooper Creek, east of Wallace, Idaho	No obvious damage

Four to eight seedlings from each of the seven half-sib families were placed at random in a 200 cell pine-cell rack. The minimum number of seedlings per stand was 24 (4 seedlings of each of 6 families) and the maximum was 34. Next, 200 of the second- and third-instar larvae were placed on the materials, one to a seedling, and then observed closely for 1 week. Notes were taken on general behavior of the larvae for 1 week, and after 3 weeks the seedlings were taken from their random position and rearranged by stand and mother tree. At this time, degree of defoliation was estimated as percent of available foliage consumed on each seedling. Independent estimates of damage were obtained by two researchers and were averaged to obtain a score for each individual seedling. Each seedling was ranked on a scale from 1 to 10 as follows: An estimated percentage defoliation of 0 to 10 was scored as 1 and so on up to 91 to 100 percent being scored as 10. The scores were subjected to analysis of variance according to Snedecor (1956). Variation among families for defoliation was analyzed by chi-square as was percentage of seedlings from a stand exhibiting bud damage resulting from budworm feeding.

RESULTS

Dispersion of the larvae on the 1-0 Douglas-fir seedlings was most complete. Even though one larva was placed on each tree, most did not stay where placed. The larvae remained very active for about 10 days at which time all those not establishing permanent feeding sites had been lost by simply crawling from the pine cell rack. The number of established larvae (pupated) was not recorded in this preliminary test, but it is known to have been about 10. On certain trees larvae built shelters very quickly by webbing together needles or just spinning a shelter entirely from silk. In other cases larvae were placed on a given tree upwards to 50 times but no shelters or feeding ever occurred on that tree. On other trees many different larvae tried repeatedly to establish feeding sites, but in the end none stayed. In the beginning all larvae that attempted to spin shelters did so at the tips of the trees; however, after 10 days a few larvae settled in the lower parts of the first-year crowns and fed to pupation.

During the dispersion process of the second- and third-instar larvae, the following territorial behavior patterns were observed: (1) Display by the individual occupying the territory (a shelter of his construction), and (2) a quick and uniform response by the intruder. Typically, when an active larva in a shelter was approached by a wandering larva, the established larvae would display by thumping its posterior on its shelter floor. At times, this motion was so violent that the entire seedling would shake. Occasionally, the established larva would also "stamp its feet" rather than use its posterior or do both, but not at the same time. Either display generally elicited the same reaction in the approaching larva. Upon receipt of an assumed message, the intruding larva would quickly drop from the area. Since the intruder was usually aligned with a needle, most often it would simply crawl to the end of a needle and spin down.

The analysis of variance showed a significant main effect (5 percent level) due to stands (table 2). Mean values of progeny defoliation (table 3) showed that stand 8 appeared to be different. Progeny from stand 8 trees incurred about two-thirds the defoliation of the average for the entire test and about one-half as much as the most highly defoliated progeny.

Table 2.--*ANOVA of defoliation by* Choristoneura occidentalis *of first-year Douglas-fir seedlings*

Source	d.f.	SS	M.S.	F
Stands	6	125.97	21.00	2.24*
Seedlings/stand	193	1809.87	9.38	
Total	199			

*Significant at 5-percent level.

Table 3.--*Average defoliation rating and bud damage resulting from* C. occidentalis *feeding on a Douglas-fir progeny test*

Stand	Number seedlings	Average defoliation rating	Percent debudded	Budworm status at seed collection
1	34	3.38	0.94	No obvious damage
2	28	5.18	.89	No obvious damage
3	31	3.52	.58	No obvious damage
4	28	3.61	.75	Light damage
8	31	2.55	.65	Very severe damage
20	24	4.58	.96	No obvious damage
23	24	3.58	.75	No obvious damage
Totals	200	3.73	.79	

Percent debudded:
χ^2 = 18.06
d.f. = 6
Probability of larger χ^2 = 0.01

Variation among stands in the percentage of buds damaged also was significant. The lowest amount of damage was 58 percent and the highest was 96 percent (table 3).

Progenies of individual trees within stands also exhibited great variation in defoliation (tables 4 and 5). Families from stand 8 differed significantly from family to family, whereas families from stand 2, the most susceptible stand, did not.

Table 4.--C. occidentalis *defoliation rating of progeny from individual Douglas-fir trees exhibiting full crown during a severe budworm outbreak (stand 8)*

Cone bearing tree	Seedling defoliation rating				ΣX	$\bar{X}$	ΣX^2	χ^2
9	1	1	1	7	10	2.5	52	10
5	9	3	7	1	20	5.0	140	8
4	7	1	1	1	10	2.5	52	10
8	1	1	1	1	4	1.0	4	0
3	4	2	1	1	8	2.0	22	3
6	1	1	2	1	5	1.25	7	4
10	3	1	1	1	6	1.5	12	2
Totals[1]					63	9.0	174	37

All trees (pooled):
χ^2 = 37.0
d.f. = 21
Probability of larger χ^2 = 0.025

Individual cone bearing trees:
χ^2 = 19.33
d.f. = 6
Probability of larger χ^2 = 0.005

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[1] Calculations according to Snedecor (1956, p. 234).

Table 5.--C. occidentalis *defoliation rating of progeny from individual Douglas-fir trees growing in stand free of budworm (stand 2)*

Cone bearing tree	Seedling defoliation rating				ΣX	$\bar{X}$	ΣX^2	χ^2
23	5	5	8	5	23	5.75	139	1.17
28	7	5	1	10	23	5.75	175	7.43
29	9	1	8	3	21	5.25	155	8.52
12	10	9	1	2	22	5.50	186	11.82
14	2	3	3	9	17	4.25	103	7.24
16	1	9	9	10	29	7.25	263	7.28
20	3	3	2	2	10	2.50	26	.40
Totals[1]					145	20.71	209.43	43.86

All trees (pooled):
χ^2 = 43.86
d.f. = 21
Probability of larger χ^2 = 0.005

Individual cone bearing trees:
χ^2 = 10.11
d.f. = 6
Probability of larger χ^2 = 0.20

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[1] Calculations according to Snedecor (1956, p. 234).

DISCUSSION

The two significant results of this preliminary test are (1) western spruce budworm can be easily collected and distributed to Douglas-fir progeny tests and made to feed sufficiently to establish data, and (2) genetic variation in defoliation among stands suggests that feeding preference of budworm is apparently influenced by an inherited factor, or factors, in the Douglas-fir host. This conclusion lends tentative support to the idea that budworm and Douglas-fir have coevolved an interactive genetic system, as does the fact that of the seven stands tested only stand 8 has been exposed to recent heavy defoliation by budworm. Trees supplying seed from this stand were those that were being relatively lightly defoliated. Also, these same stands exhibited patterns of variation for several other adaptive traits (Rehfeldt, in press) that were very similar to those reported in this paper.

The great amount of seedling-to-seedling variation (tables 4 and 5) in level of defoliation within maternal populations was not unexpected. Rehfeldt (in press) reported high amounts of this kind of variablity for six physical traits of inland Douglas-fir. Although the variation within maternal populations could be due to erratic feeding behavior, it is just as likely due to within-family genetic variance. Also, we know that larvae visited all the seedlings because several to numerous strands of silk were observed on the needles of all seedlings and budworm larvae are known to spin silk wherever they go (Harvey 1957). One certainly must concede the possibility that the variation within families is due, in large part, to genetic variation along with the stand related genetic variation. A larger test is certainly called for.

The amount of budworm feeding on buds varied with stand, but stand 8 exhibited the second lowest level (table 3). The lowest level was recorded for stand 3, which was free (no obvious damage) of budworm during the seed collection period. Progeny from stands similar to stand 3 exhibited as high as 96 percent bud feeding. These results indicate that the budworm:Douglas-fir interaction is complex.

The territorial behavior seemed to be most effective at insuring maximum dispersal of the larvae and could play an important role in population regulation of budworm (Klomp 1964). Knowledge of this behavior could also be important in designing future progeny tests.

CONCLUSIONS

Results of this preliminary test suggest that inheritance may be involved in the modification of *C. occidentalis* behavior by Douglas-fir genotypes. Thus, the budworm: Douglas-fir system apparently does contain coevolved genetic interaction. *Choristoneura occidentalis* can be manipulated in a laboratory setting to feed on Douglas-fir progeny tests. Methods can be developed to measure defoliation and other kinds of damage. Large numbers of larvae can be easily collected and quickly distributed over the materials to be tested. Finally, second- and third-instar larvae are largely self-dispersing, provided population levels exceed available feeding sites, due to the territorial behavior of *C. occidentalis*.

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Research Note

USDA FOREST SERVICE INT-265
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September 1979

PINE TISSUE AFFECTED BY BLISTER RUST DESPITE DIALYSIS BARRIER BETWEEN THE ORGANISMS IN CULTURE

A. E. Harvey[1]

ABSTRACT

Physical and chemical properties of ribonuclease were altered in pine tissue cultures exposed to the blister rust fungus in a co-culture system that prevented physical penetration of host tissues. Changes were similar to those caused by direct infection of pine stems, pine tissue cultures, and Ribes *leaves. Because they occurred in spite of interposed dialysis membranes, the changes were apparently induced by diffusion of pathotoxins of small molecular weight.*

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

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[1] Plant Pathologist located at Intermountain Station's Forestry Sciences Laboratory, Missoula, Montana 59801.

Demonstrable effects on host ribonuclease (RNase) are induced through direct parasitism by *Cronartium ribicola* J. C. Fisch. on *Ribes nigrum* L. leaves, *Pinus monticola* Dougl. tissue cultures (Harvey and others 1974b), and *P. monticola* seedling stems (Harvey 1977). These and other pathological changes occur in advance of physical penetration of the pine host (Harvey 1977; Robb and others 1974; Harvey and others 1974b). This suggests the presence of diffusible pathotoxins in white pine blister rust infections.

Ribonuclease properties were used herein as tools for demonstrating rust induced host changes in a previously developed co-culture system (Harvey and Grasham 1970). Direct penetration of the host was precluded by interposition of dialysis membranes between the parasite and its pine host.

MATERIALS AND METHODS

Pine tissue explants were removed from seedling stock derived from open-pollinated seed collected in the St. Joe National Forest in north Idaho. Seedlings were grown in nursery beds for ca. 7 years. Explant preparation and culture methods have been described (Harvey and Grasham 1970). Measurements reported here were taken from a clonal culture derived from a single seedling.

Rust inoculum for co-culturing was derived from an axenic culture isolate. This isolate is deposited with the American Type Culture Collection and is designated #PR-91. In all other respects, the co-culture technique was identical to that previously reported.

For this study, the rust was propagated in a basal medium of known composition (Harvey and Grasham 1974a) fortified with 10 mg/l vitamin-free, casein acid hydrolysate as a source of amino acids.

Co-cultures were produced by placing whole, 30-day-old axenic rust cultures onto dialysis membranes (pore size 4.8 micrometer) covering host tissues imbedded in the culture medium (fig. 1). This was done 90 days after initial establishment of the host cultures. Co-cultures were incubated for an additional 150 days (16 at 20° C, 400 fc fluorescent light, and 8h at 5° C, no light).

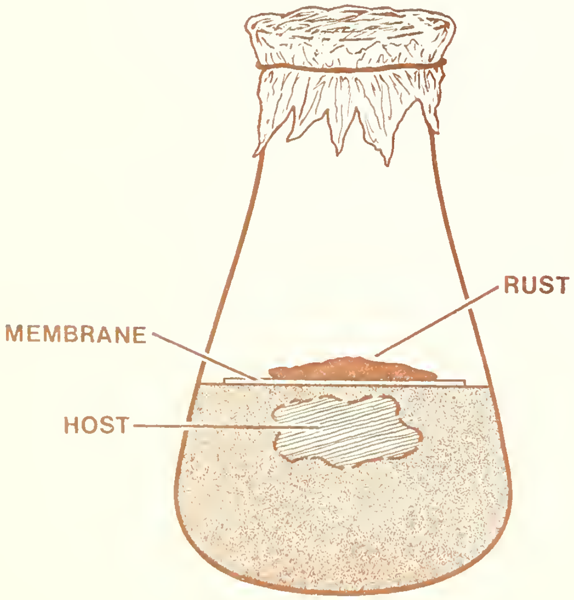

Figure 1.--Diagram of host-rust co-culture system used in this study. Cultured in 125 ml flasks covered with cellophane (Harvey and Grasham 1970).

Host tissues used for extraction were prepared by gently removing whole cultures from the flasks and washing away all adhering agar substrate by rinsing with distilled water. Approximately 2.0 g (one whole, undamaged culture) was extracted immediately after rinsing.

Rust tissues used for extraction were removed from the membrane co-cultures at the time host tissues were prepared. These tissues were rinsed in distilled water, combined with 5-10 identical cultures (minimum of 0.5 g fresh weight) and extracted immediately.

Healthy host tissues were produced exactly the same as rust exposed host tissues except that the membranes were not inoculated. Handling of tissues in preparation for extraction was accomplished with scrupulously cleaned instruments and vessels while wearing disposable plastic gloves. All possible care was exercised to prevent contamination of samples with ribonuclease from any external source.

Enzyme assays were as described by Scrubb and others (1972). One unit of RNase is defined as the quantity catalyzing an increase in A_{260nm} of 1.0 under standard conditions of assay, and specific activity in units/mg protein. Specific activities of other hydrolases are expressed as ΔOD at the appropriate wavelength/mg of protein.

Because the tissues used herein were somewhat different than those for which the measurement methods were developed, all measurements were based on at least three separate extractions of different samples, with minor changes in the extraction procedures. Enzyme assays were also carried out in triplicate, with minor changes in the preparation or assay procedure. The results reported here are based on the optimal enzyme activity achieved.

RESULTS AND DISCUSSION

Although conditions prevailing during extraction procedures and in RNase reaction vessels used in this study were generally unfavorable to hydrolytic activity of deoxyribonuclease (DNase), phosphodiesterase, alkaline phosphatase, and acid phosphatase, their activities were measured. Table 1 summarizes typical values when tissue extracts were assayed under optimum conditions for each. Rates of hydrolytic activity in rust-exposed pine tissues were lower than in tissues not exposed to the rust. This indicates that any increases in RNA hydrolysis products are derived from RNase activity.

Table 1.--*Changes in the activities of enzymes (other than ribonuclease) capable of hydrolyzing the phosphodiesterase bond, from healthy and blister-rust exposed pine tissue cultures*

Tissue	Hydrolytic enzyme ΔOD at appropriate wavelength per mg protein			
	DNase[1]	Acid phosph[2]	Alk phosph	Phospho-diesterase
Healthy (unexposed) pine tissue culture	14.8	23.9	7.7	0.0
Rust-exposed-(5 mo) pine tissue culture	9.4	18.3	3.4	0.0

[1] Deoxyribonuclease.
[2] Phosphatase.

The effects of pH on activity of RNase extracts from various tissues is shown in figure 2. Both rust and rust-exposed pine tissues had higher specific activities at their optimum pH than healthy host tissues. The rust-exposed pine tissue enzyme preparations were also more stable to pH change than those of either rust or healthy host tissue. The pH optimum (4.5) of these preparations were identical for all tissues.

Table 2 shows relative rates of hydrolysis of four radiolabelled homoribopolymers resulting from exposure to RNase preparations from rust, rust exposed pine, and healthy pine tissue cultures. Total activity was highest in rust tissues and lowest in healthy pine tissue. A similar order was shown in figure 2. The ability of pine tissue RNase extracts to break down these substrates changed dramatically when the tissue cultures were exposed, via the dialysis membrane, to the rust fungus. Most striking of these effects was a doubling in the hydrolysis rate of polyadenylic acid and halving the hydrolysis rate of polyuridylic acid. Rust RNase was also highly active against polyadenylic acid.

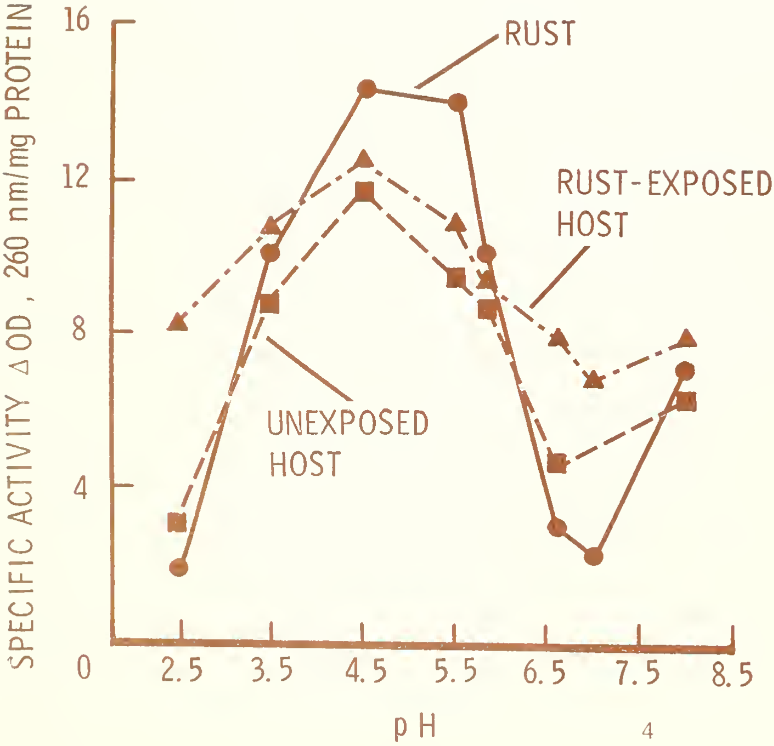

Figure 2.--pH activity curves for RNase extracts of rust, rust-exposed, and healthy pine tissue cultures, after 5 months in co-culture. Assay buffers were: Na_2HPO_4-citric acid, pH 2.5-4.5; KH_2PO_4-NaOH, pH 5.5-7.0; Tris-Hcl, pH 8.0-8.5.

The effect of diethylpyrocarbonate on the activity of RNase extracted from these tissues was also striking. The ability of both rust and healthy host tissue RNase to hydrolyze polyinsinic acid was highly sensitive to the presence of this inhibitor. However, RNase from host tissues that were exposed to the rust was more stable (table 3).

Table 2.--*Hydrolysis of radiolabeled polynucleotides by RNase extracts from blister rust, rust-exposed, and healthy pine tissue cultures*

Tissue	Hydrolysis dpm/g protein x 10^{-3}				Total dpm
	Poly (A)[1]	Poly (U)	Poly (I)	Poly (C)	
Healthy (unexposed) pine tissue culture	504	497	79	3	1,087
Rust-exposed-(5 mo) pine tissue culture	1,100	231	89	1	1,421
Rust mycelium	2,488	679	478	0	3,645

[1] Abbreviations used are: poly (A), poly (U), poly (C), and poly (I), polyadenilic, polyuridilic, polycytidilic, and polyinosinic acids, respectively.

Table 3.--*Diethylpryocarbonate (DEP) inhibition of hydrolysis of ^{14}C-labeled polyinosinic acid by RNase from blister rust, rust-exposed, and healthy pine tissue cultures*

Tissue	Hydrolysis dpm/mg protein		DEP inhibition percent
	-DEP	+DEP	
Healthy (unexposed) pine tissue culture	19,200	1,500	80
Rust-exposed-(5 mo) pine tissue culture	509,000	226,000	67
Rust mycelium	16,000	--	100

Evaluations of temperature stability showed that the highly active RNase extract from rust tissues was highly temperature sentitive, extract from healthy host tissues was relatively stable, and extract from rust exposed host tissues was possibly slightly less stable than from the healthy host (table 4). Heat sensitivity of RNase from blister rust-infected tissues has been reported elsewhere (Harvey 1977; Harvey and others 1974b).

Table 4.--*Thermal stability for RNase from blister rust, rust-exposed, and healthy pine tissue cultures*[1]

Tissue	Specific activity ΔOD 260nm/mg protein 10 min 0° C	 10 min 80° C	Percentage inhibition after heating
Healthy (unexposed) pine tissue culture	2.9	1.3	55
Rust-exposed-(5 mo) pine tissue culture	3.3	1.6	59
Rust mycelium	3.0	0.2	93

[1] Enzyme extracts were treated by holding at 80° C for 10 min, cooling to 0° C, then assaying for residual activity.

CONCLUSIONS

The results presented herein demonstrate that some of the characteristic changes in host RNase activity resulting from interactions with various obligate parasites (Chakravorty and Shaw 1977; Harvey and others 1974b; Scrubb and others 1972; Reddi 1966; Diener 1961) may also occur when the interaction process is limited to the exchange of small molecular weight metabolites. They confirm that one or more diffusible pathotoxir are produced by the blister rust fungus (Harvey and others 1974b; Robb and others 1974; Harvey 1977) in the presence of its pine host.

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November 1979

RELATIONS BETWEEN INSIDE AND OUTSIDE BARK DIAMETER AT BREAST HEIGHT FOR DOUGLAS-FIR IN NORTHERN IDAHO AND NORTHWESTERN MONTANA[1]

Robert A. Monserud[2]

ABSTRACT

Linear regression was used to predict breast high diameter inside bark from diameter outside bark for inland Douglas-fir. Observations were obtained from 777 trees, covering a wide range of sizes and ages, from northern Idaho and northwestern Montana. These predictions were compared to earlier studies of Douglas-fir bark thickness sampled in Washington, Oregon, and the northern Rocky Mountain region; similar results were obtained. Indirect estimates of bark growth are derived and implications for stand simulation modeling are discussed. Bark growth was estimated to comprise approximately 25 percent of total basal area growth for inland Douglas-fir.

KEYWORDS: *Pseudotsuga menziesii*, bark thickness, bark growth, bark ratio, diameter inside bark estimation.

Estimates of inside bark diameter are often useful for determining the peeled wood volume of a tree. Preliminary results from a current study to model volume loss in top-killed trees (Monserud 1979) indicate that superior estimates of volume loss are obtained when a cylindrical form factor based on inside rather than outside bark diameter is used to estimate the parameter in the Behre hyperboloid described by Bruce (1972). Indirect estimates of bark thickness and bark growth also can be derived from the relations between inside and outside bark diameters.

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[1] The research reported here was financed in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

[2] Research forester, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

A specific need for estimated bark growth in stand simulation modeling was identified by Stage (1973) and Cole and Stage (1972). Because the diameter growth model they discussed only predicts wood growth, an estimate of future bark growth is needed to properly predict future diameter outside bark. Ignoring bark growth can lead to considerable bias in lengthy simulations, because predictions of wood growth will be based on an underestimate of outside bark diameter.

Interest may also be centered on obtaining estimates of past outside bark estimates (Johnson 1955, 1956; Spada 1960). The same procedures used to estimate future inside diameters can be used to predict past inside diameters--and usually more accurately, for the tree leaves a record of past inside bark wood growth.

This note presents breast height estimates of inside bark diameter, bark thickness, and the ratio of outside to inside bark basal area for inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Mirb.] Franco) growing in the Northern Rocky Mountains of Idaho and Montana.

METHODS

Measurements were obtained from 141 plots (fig. 1) located in seven national forests in northern Idaho and northwestern Montana (Kaniksu, Coeur d'Alene, St. Joe, Clearwater, and Nezperce in Idaho and Kootenai and Lolo in Montana). The plots were established in the summer and fall of 1976 to provide stem analysis data for a site index and height growth study for inland Douglas-fir (Monserud 1978). A total of 777 trees were measured, with a range in outside bark diameter at breast height (DOB) of 0.6 to 41.9 inches (1.5 cm to 106.4 cm).

Field Procedure

1. Plots were selected to cover a wide range of slopes, aspects, elevations, and habitat types. Suitable site trees were the three largest healthy dominant trees on an approximately 1/2-acre plot that was representative of the growing conditions in the stand. Site trees could have no sign of early suppression or damage, judging from increment cores. Three additional Douglas-fir from the nondominant crown classes were measured on each plot.

2. The selected trees were measured to the nearest 0.1 inch (0.25 cm) for diameter outside bark at breast height (4.5 ft; 1.37 m) using a diameter tape.

3. The selected trees were then felled and sectioned at breast height. Two inside bark diameter measurements were made: the largest diameter (DIB_1) and the perpendicular diameter (DIB_2) were measured to the nearest 0.1 inch (0.25 cm).

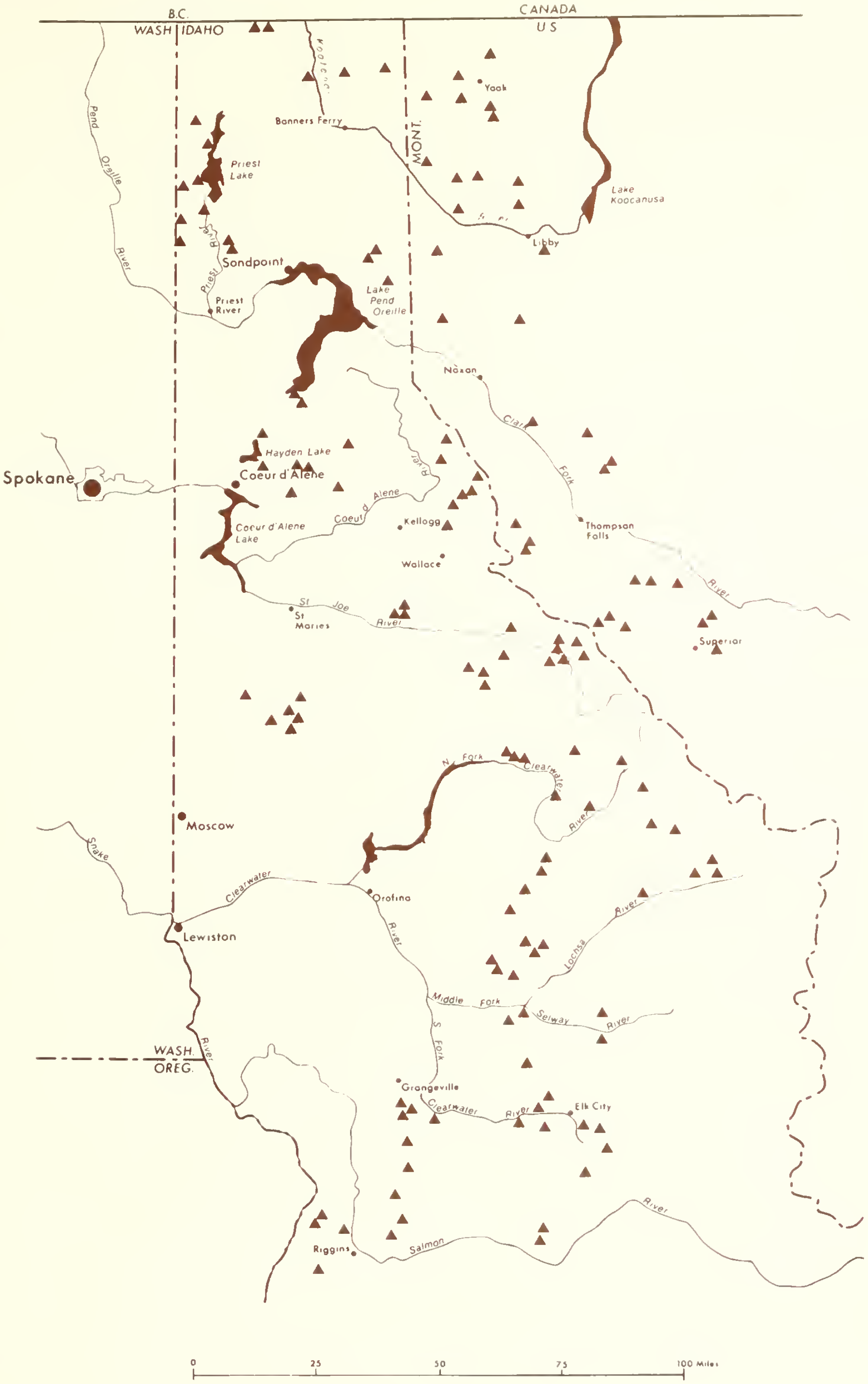

Figure 1.--Douglas-fir site index study plot locations.

ANALYSIS

The inside bark diameter (DIB) used in this analysis is the geometric mean diameter proposed by Brickell (1976):

$$DIB = \sqrt{DIB_1 \cdot DIB_2}$$

This diameter will produce the correct cross-sectional area when used in the formula for the area of a circle, assuming that the breast high section is elliptical. Because the trees measured in this study were not very eccentric,[3] the difference between the geometric mean diameter and the arithmetic mean diameter was slight.

Linear regression was used to predict geometric mean inside bark diameter as a function of various transformations of diameter outside bark (DOB); the transformations used were: DOB^{-2}, DOB^{-1}, $DOB^{1/2}$, DOB, DOB^2, DOB^3, and ln (DOB). The regression coefficient of the DOB term was most significant; no other regression coefficients were significant when included with the DOB term in the multiple regression. This procedure resulted in a prediction equation of the following form:

$$DIB = b_0 + b_1 \cdot DOB \tag{1}$$

where b_0 and b_1 are regression coefficients.

An examination of the residuals of (1) revealed a moderate tendency towards heteroscadisticity: variation increased with diameter. Because the resulting intercept term (b_0) was not significantly different than zero ($\alpha = 0.05$ level), the regression was refit through the origin, using the ratio of means estimator appropriate for data having variance proportional to the independent variable (Ek 1971). This procedure resulted in the following regression equation:

$$DIB = 0.8694 \cdot DOB \tag{2}$$

Statistics for this regression are: standard error (SE) = 0.53 inches (1.35 cm), the standard error of the regression coefficient is $SE(b_1) = 0.0022$, and the standard deviation of the percentage residuals is 3.5 percent. A graph of equation (2) and the 777 observations is given in figure 2.

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[3] The ratio of DIB_2 to DIB_1 had an average value of 0.946 with a standard deviation of 0.04.

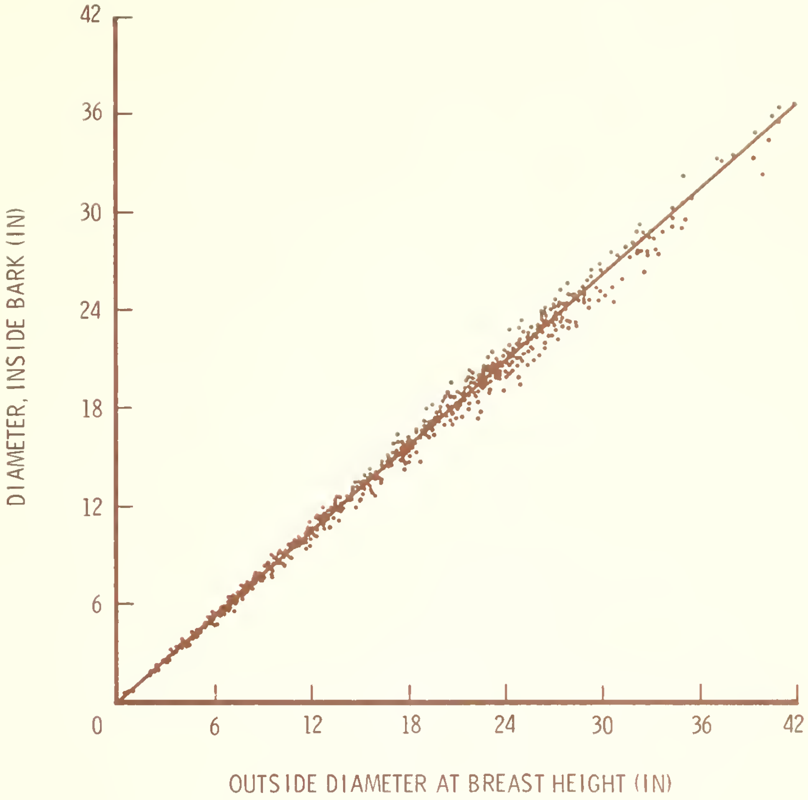

Figure 2.--Inside vs. outside bark diameter at breast height for 777 observations of inland Douglas-fir in northern Idaho and northwestern Montana. Regression equation (2) is plotted as a solid line.

DISCUSSION

Double Bark Thickness

Because double bark thickness (BARK) is simply the difference between the outside and inside bark diameters, the parameters in equation (1) can be transformed to allow for estimating bark thickness directly:

$$BARK = -b_0 + (1-b_1) \cdot DOB \qquad (3)$$

where b_0, b_1, and DOB are as defined in equation (1).

When the slope estimate given in equation (2) is used in equation (3) with the assumption that $b_0 = 0$, the following equation results:

$$BARK = 0.1306 \cdot DOB \qquad (4)$$

Using equation (4) allows the results of this study to be compared to earlier studies of Douglas-fir bark thickness in eastern Washington and Oregon and in the Northern Rocky Mountain Region.

Spada (1960) reports on a sample of 2259 inland Douglas-fir from the east side of the Cascade Range. His equation for bark thickness was:

$$BARK = 0.0704 + 0.1176 \cdot DOB \qquad (5)$$

Johnson (1955) sampled 527 coastal Douglas-fir (*P. menziesii* var. *menziesii*) on the west side of the Cascade Range and obtained the following bark thickness equation

$$\text{BARK} = \begin{cases} -0.60 + 0.154 \cdot \text{DOB} & \text{if DOB} \geq 10.0 \\ 0.0 + 0.094 \cdot \text{DOB} & \text{if DOB} < 10.0 \end{cases} \qquad (6)$$

Graphs of equations (4) through (6) and the observations used in the current study are all given in figure 3. It is apparent that the slope for the northern Idaho dataset (0.1306) is intermediate between the slopes for the west and east sides of the Cascades (0.154 and 0.1176, respectively). It is also apparent that little difference exists between the results of these three studies, when viewed in relation to the natural variation in bark thickness.

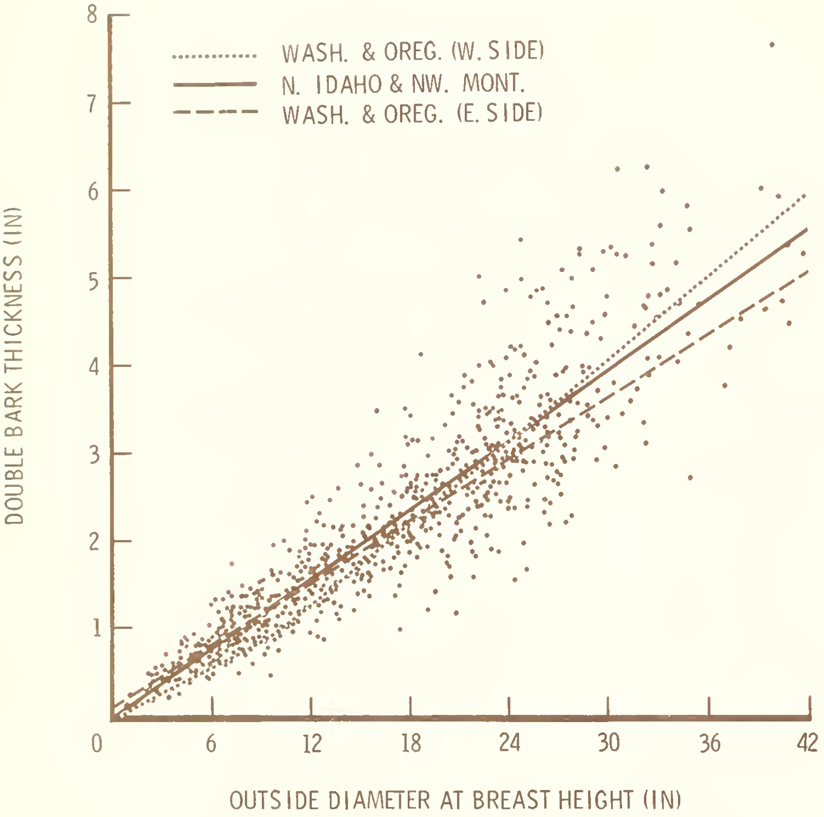

Figure 3.--Double bark thicknes vs. outside bark diameter at breast height for 777 observations of inland Douglas-fir i northern Idaho and northweste Montana. Bark thickness equations (5) and (6) are plotted with equation (4) to allow fo comparison with results from Washington and Oregon.

Finch (1948) reports on a study of bark thickness for 12 species growing in the Northern Rocky Mountain Region. Based on a limited sample of 156 observations of inland Douglas-fir, Finch provides an estimate of bark growth that can be transformed into the following relationship:

$$\text{BARK} = 0.134 \cdot \text{DOB} \qquad (7)$$

This estimate agrees almost exactly with the results obtained in the current study (equation 4), which was based on observations from the same geographic area.

Basal Area Ratio

Cole and Stage (1972, p. 8) point out that the ratio of DOB^2 to DIB^2 (termed BAR, basal area ratio) is needed to properly predict future diameter outside bark from present diameter outside bark and estimated area of wood growth (inside bark). Using the 777 Douglas-fir observations, the average of this basal area ratio is:

$$BAR = DOB^2/DIB^2 = 1.3306 \qquad (8)$$

The standard deviation is 0.095. BAR vs. diameter outside bark is plotted in figure 4.

An attempt to explain some of the residual variation in BAR proved fruitless. Using tree characteristics (age, height, crown ratio, basal area percentile), site characteristics (slope, aspect, elevation, habitat type, site index), and stand density measures (basal area per acre, crown competition factor), at most 2 percent of the residual variation was explained by any variable.[4]

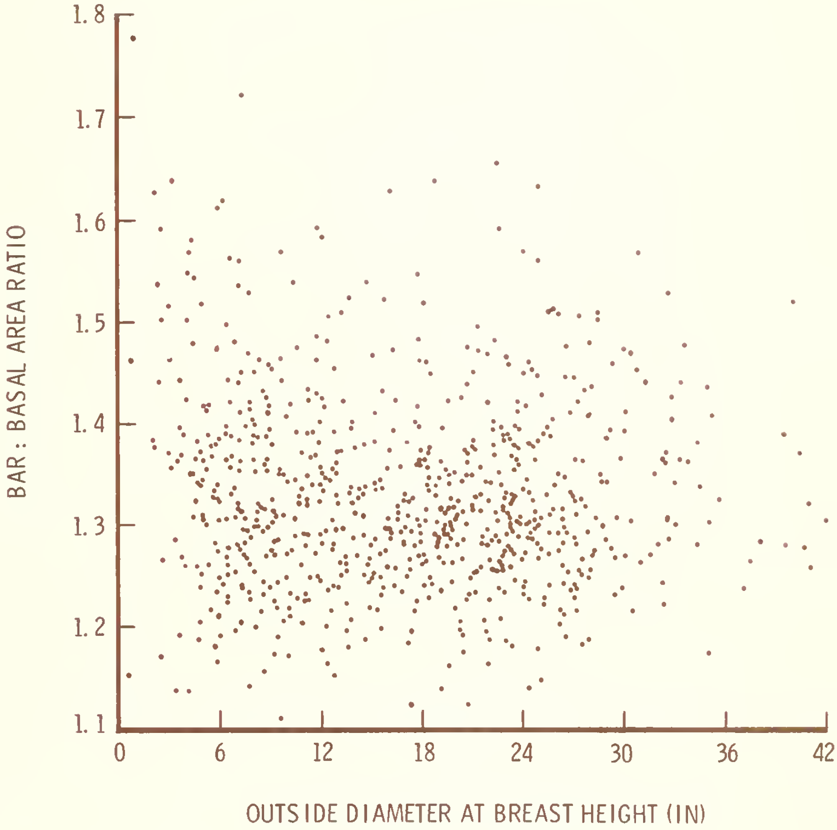

Figure 4.--Ratio of outside to inside bark basal areas (BAR) vs. outside bark diameter for 777 observations of inland Douglas-fir. BAR has an average of 1.3306 and a standard deviation of 0.095.

Bark Growth

Bark growth is an extremely difficult variable to measure. Indirect estimates can be obtained, however, using the relationships between inside and outside bark diameters and the measured wood growth. Indeed, Johnson (1955, 1956), Spada (1960), and Finch (1948) emphasize obtaining an estimate of bark growth so that an accurate estimate of past diameters (outside bark) can be obtained.

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[4] Similar results were obtained when this same set of potential predictor variables was used to reduce the residual variation in equation (2).

Because BAR-1.0 is the corresponding estimate of bark basal area growth as a percent of wood basal area growth, it is apparent from equation (8) that bark growth is approximately one-third of wood growth for Douglas-fir, and one-fourth of total basal area growth. To paraphrase Johnson (1956), if bark growth is ignored in estimating future (or past) outside bark diameters, the resulting bias would be appreciable.

The preceding estimate of bark growth is valid only if the ratio of outside to inside bark basal area does not vary with time. Based on the rather weak relationship between BAR and tree age (2 percent of the residual variation in BAR was explained by age), this study did not provide evidence that BAR did vary over time. Of course, repeat measurements on the same trees over time would be necessary to properly examine this question, and such information was not obtainable in this study.

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SPONTANEOUS AND PILOTED IGNITION OF ROTTEN WOOD

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ABSTRACT

Spontaneous and piloted ignitions of rotten wood samples from ponderosa pine (Pinus ponderosa), *Douglas-fir* (Pseudotsuga menziesii), *and subalpine fir* (Abies lasiocarpa) *were investigated in a specially designed ignition furnace. Minimum heat flux intensities required to produce ignition, times to ignition, and temperatures at times of ignition are given.*

KEYWORDS: forest fuel ignition, rotten wood ignition, ignition, pilot ignition, spontaneous ignition.

The process of decay transforms sound wood into a "punky" material that fire managers have long recognized as one of the most troublesome forest fuels. This material, present in all forest types, is important not only because of the ease with which it forms firebrands, but also for its suitability as a firebrand recipient. It is as a recipient where its ease of ignition and the fire holding properties of this material cause fire control forces the most concern. Punky wood has been known to harbour a glowing ignition process for days or even weeks with little or no outward sign of combustion. The necessary environmental conditions may then develop to produce flaming combustion and an eventual problem fire.

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The timber industry is acutely aware of the ignition potential of the rotten wood present at nearly all logging sites. The susceptibility of rotten wood to ignition by carbon particles, hot gases, and contact with hot surfaces was the subject of many early fire research investigations (Doyle 1926; Space 1927; Wright 1932; Fairbanks and Bainer 1934). More recently, power saw ignition of punky wood and other forest floor fuels, particularly in the Pacific Northwest, became of great concern to protection agencies and lumbering concerns. As a result, in 1974, the Northwest Forest Fire Council formed a Power Saw Spark Arrester Committee composed of representatives of the Federal and State Protection agencies in the States of Washington, Oregon, and California, the Washington and Oregon Forest Protection Associations, and several forest industries. The Engineering Committee of the Power Saw Manufacturer's Association was contacted and cooperative efforts were begun to alleviate the problem.

The primary objective of the Power Saw Spark Arrester Committee was to determine acceptable temperature standards for power saw exhaust systems. Instrumentation and procedures developed at the Northern Forest Fire Laboratory for the investigation of ignition properties of fine forest fuels were directly applicable to this determination (Stockstad and Lory 1970; Stockstad 1972, 1973, 1975, 1976). The portions of a study utilizing rotten wood as the test fuel are reported in this paper. The data and conclusions presented were used by the committee to formulate new temperature standards for power saw exhaust systems. These standards were in turn used by the National Society of Automotive Engineers, the Departments of Natural Resources of the States of Washington and Oregon, and the USDA Forest Service to adopt or amend regulatory standards for power saw exhaust systems (National Society of Automotive Engineers 1976; Washington State Department of Natural Resources 1976; Oregon State Department of Natural Resources 1976; USDA Forest Service 1976).

OBJECTIVES

The objectives of this study were to determine:

1. The time required for ignition to occur in rotten wood,

2. The surface temperatures at the onset of ignition, and

3. The effect of fuel moisture content and initial heat source intensity on items 1 and 2 above.

PROCEDURES

The Stockstad-Lory ignition furnace (Stockstad and Lory 1970; Stockstad 1972, 1973) was used for all testing. Both spontaneous and pilot ignition were studied using a 2.54 cm by 0.25 cm by 0.25 cm (1-inch by 0.1-inch by 0.1-inch) section of rotten wood. Spontaneous and piloted ignition tests were replicated 20 times for each moisture level and furnace temperature under consideration.

Tree species used in the testing were ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Psuedotsuga menziesii*), and subalpine fir (*Abies lasiocarpa*). Ponderosa pine and Douglas-fir samples both were obtained from the Blue Mountain and Mill Creek areas in the vicinity of Missoula, Montana; subalpine fir samples were obtained near Lolo, Montana.

Samples were obtained by cutting 0.25 cm (0.10-inch) thick slabs from visually uniform pieces of rotten wood. A standard 35.56 cm (14-inch) band saw with a special 24-tooth per 2.54 cm (1-inch) blade was used for this operation. The fine tooth blade was necessary to assure a successful cut through the fragile sample. The slab was then cut into 0.25 cm by 0.25 cm (0.10-inch by 0.10-inch) strips using a modified high speed (30,000 rpm) hand tool to drive a miniature circular saw 0.013 cm (0.005-inch) thick and 2.54 cm (1-inch) in diameter. This same tool was used to cut the strips into 2.54 cm (1-inch) lengths for testing. The use of this special saw was the only successful method that could be found to cut strips from the sample material. All samples were kept at an ambient laboratory air temperature prior to conditioning for testing.

Prepared sections were placed in conditioning cabinets containing saturated salt solutions (Schuette 1965) to provide three moisture levels of approximately 6, 14, and 23 percent. Moisture content was determined on an oven-dry weight basis using the conventional oven dry method.

The minimum furnace temperature used for each moisture content in the testing program was that at which ignitions were not observed in 20 trials. Each trial was allowed to continue until ignition occurred or for a 3-minute time interval. (Preliminary testing had indicated ignition would usually occur in less than a 1-minute interval.) Furnace temperature then was raised 10°C and another series of 20 tests were observed. This procedure was repeated until a furnace temperature was reached at which all samples of a given species and moisture level ignited.

Sample temperature was measured by a 3-mil platinum vs platinum 10-percent rhodium thermocouple placed on the forward end of the sample. The ignition chamber temperature, synonymous with furnace temperature, was measured by a similar thermocouple approximately 3 mm (0.118 inches) from the sample thermocouple (Stockstad 1972). Both thermocouples were connected to a recorder and the output was plotted against time.

Three points on the plotted thermocouple traces from a spontaneous ignition test were considered in the analysis:

1. Point one.--The point at which the sample thermocouple trace crossed and exceeded the ignition chamber trace was considered to be the beginning of the exothermic reaction. This point was considered to be indicative of the lowest temperature at which the ignition process could occur.

2. Point two.--The second significant change in the sample thermocouple trace was the point where the exothermic reaction increased in intensity and resulted in an abrupt rise in the temperature of the sample. This point was considered to represent the time and temperature at which the spontaneous ignition process would always continue to the end result--visible glowing.

3. Point three.--An event marker activated by the test operator that indicated the time and temperature at which visible glowing was observed.

Pilot ignition tests were conducted in the same manner as spontaneous ignition tests, except for the introduction of a pilot flame (Stockstad 1972). Pilot ignition usually occurred at temperatures below actual furnace temperature; therefore, the beginning of the exothermic reaction, if one occurred, could not be determined by the previously described criteria. The point at which flaming ignition took place was marked by an abrupt, nearly vertical rise in the trace. For this reason, an operator-activated event marker was not necessary for the pilot ignition testing.

RESULTS

The results of the 630 spontaneous ignition tests and the 200 pilot ignition tests are given in appendix tables 1 through 6.

The minimum temperature at which spontaneous ignition occurred was 270°C (518°F) for ponderosa pine, 260°C (500°F) for Douglas-fir, and 300°C (572°F) for subalpine fir rotten wood sections. One hundred percent of all samples tested were spontaneously ignited at temperatures of 320°C (608°F) for ponderosa pine, 300°C (572°F) for Douglas-fir, and 330°C (626°F) for subalpine fir. The moisture content of the samples varied.

An increase of 10°C (18°F) in furnace temperature usually resulted in a marked increase in the number of samples that ignited. In the case of the ponderosa pine samples from Elk Ridge, a furnace temperature increase of 10°C (18°F) resulted in the probability of ignition increasing from approximately 25 percent to 100 percent; a 20°C (36°F) rise increased the probability of ignition from 0 percent to 100 percent. The probability of ignition increase was not as dramatic for the other samples tested, but remained abrupt.

Figure 1 shows the relation between the time required for spontaneous ignition to occur at the various moisture content levels of the different samples tested. The furnace temperatures at which 100 percent of all samples ignited were used for comparison.

Analysis of variance (at the 95 percent level of confidence) did not show a significant difference for the times and temperatures at spontaneous ignition among the Elk Ridge area, ponderosa pine samples having a variety of moisture contents. A significant difference did exist for both time and temperature at spontaneous ignition for all others samples and different moisture contents.

Further analysis using the Tukey's Test (Steel and Torrie 1960) revealed a significant difference to exist for all samples (other than those from Elk Ridge) in time-to-ignition between the lowest and highest moisture content samples examined. The significance also existed between the low and medium moisture contents for the ponderosa pine and Douglas-fir samples from the Mill Creek area, but not for the Douglas-fir from the Blue Mountain area nor the subalpine fir from the Lolo Creek area. For the samples from the latter two areas, the significance did exist between the medium and high moisture contents.

Tukey's Test also revealed a significant difference to exist for all samples (except the Elk Ridge samples) in the temperature at spontaneous ignition for the lowest and highest moisture content samples examined. Significant differences also existed between the lowest and medium moisture content samples in the case of ponderosa pine and Douglas-fir samples from Mill Creek, but did not exist for the Douglas-fir from Blue Mountain nor the subalpine fir from Lolo Creek. A significant difference existed for the medium and high moisture content samples of Mill Creek ponderosa pine and Douglas-fir, and the subalpine fir samples from Lolo Creek.

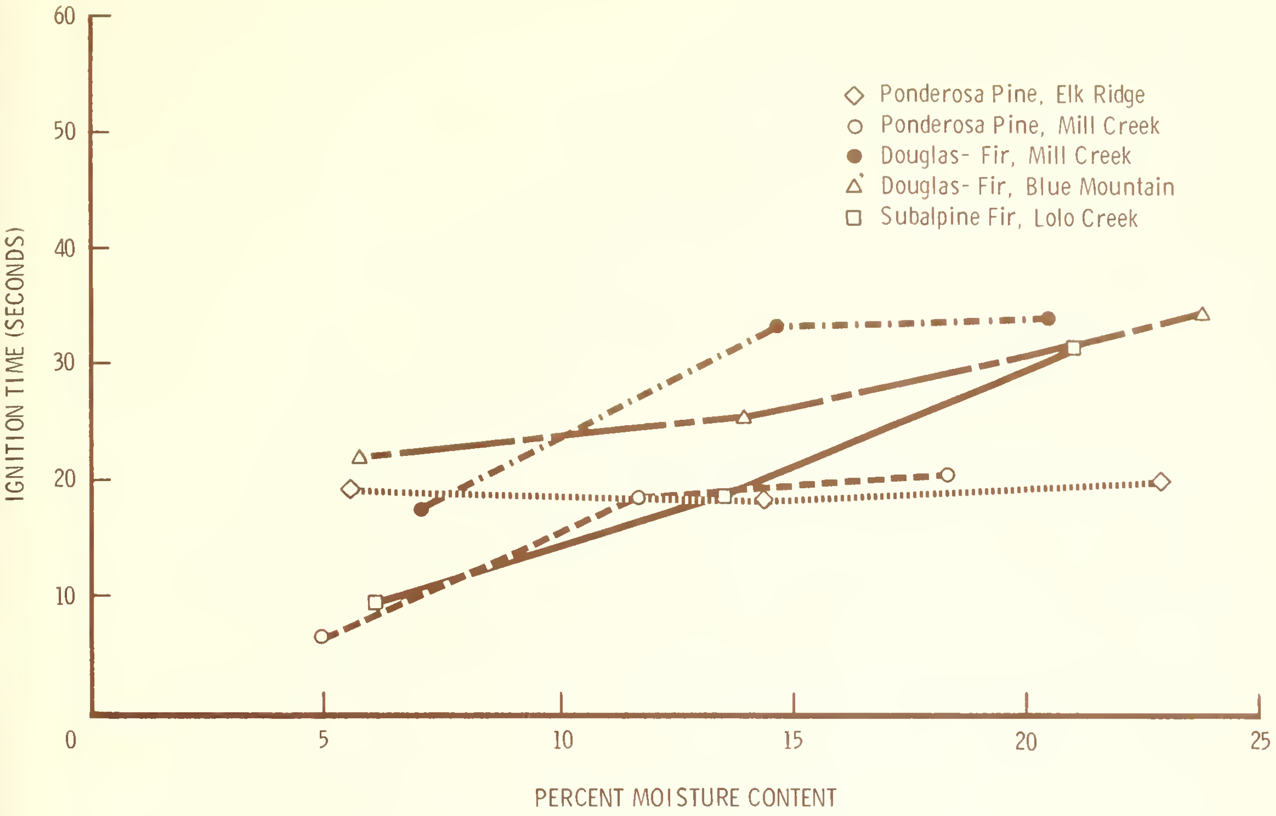

Figure 1.--Time to spontaneous ignition vs. moisture content for various rotten wood sections--100 percent of all samples igniting.

The minimum furnace temperature at which pilot ignition occurred was 250°C (482°F) for the Blue Mountain area Douglas-fir samples and 260°C (500°F) for the Elk Ridge area, ponderosa pine samples. A furnace temperature of 270°C (518°F) was necessary to produce 100 percent ignition of all samples at the moisture contents examined. A rise of 10°C (18°F) in furnace temperature resulted in an increase of ignitions from 20 to 40 percent to 100 percent for the ponderosa pine samples and a 20°C (36°F) increase, increased ignitions on the Douglas-fir samples from 0 to 5 percent to 100 percent.

Figure 2 shows the relations between the average times required for pilot ignition to occur for all moisture contents of the Douglas-fir and ponderosa pine samples tested. The furnace temperature used for comparison purposes was 270°C (518°F), the temperature at which 100 percent of all samples ignited.

Analysis of variance at the 95 percent level of confidence did not show a significant difference for either the time to, or the temperature at, pilot ignition for the ponderosa pine samples from the Elk Ridge area. The Douglas-fir samples from the Blue Mountain area exhibited a significant difference for the temperature of ignition but not for time-to-ignition. Additional analysis using Tukey's Test revealed the significance for the temperature of ignition for the Douglas-fir samples to exist for the lowest and highest moisture contents tested, but not for the lowest vs medium or the medium vs the highest moisture contents.

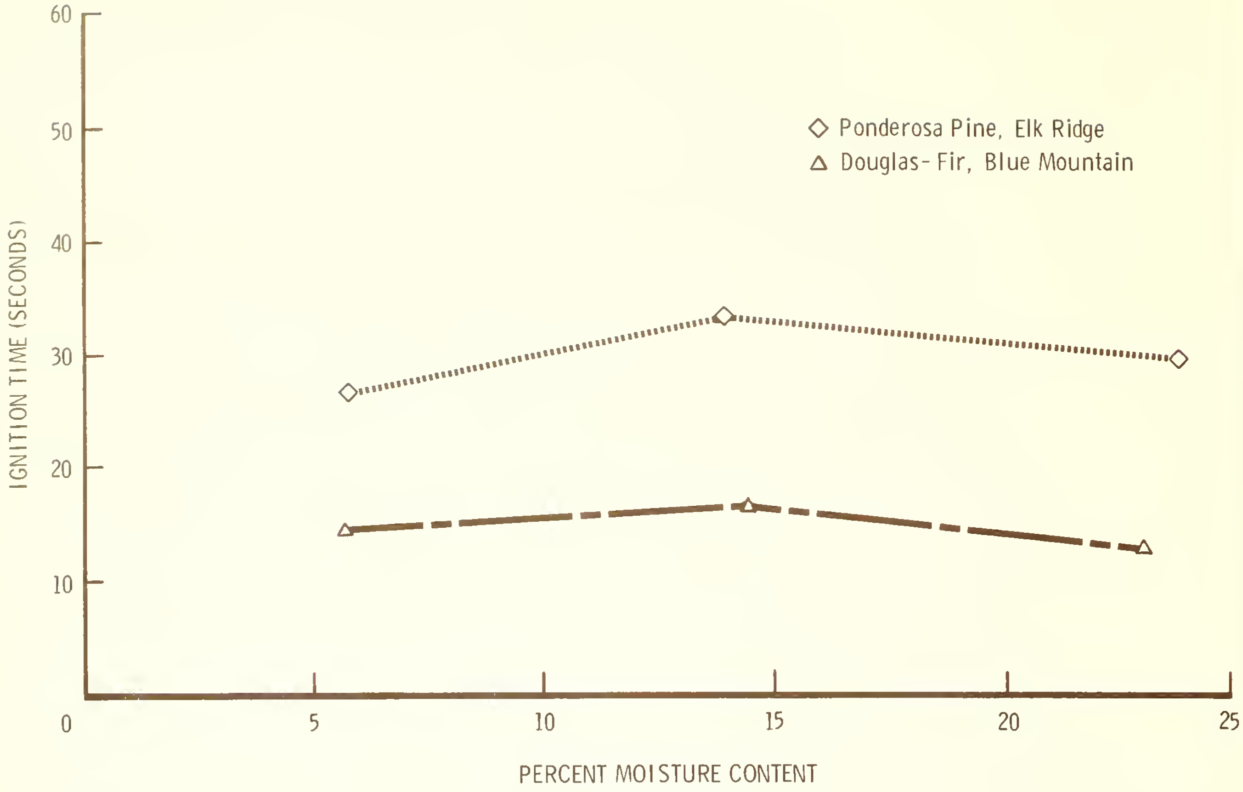

Figure 2.--Time to pilot ignition vs moisture content for various rotten wood sections--100 percent of all samples igniting.

DISCUSSION

In appendix tables 7 and 8 the average heat transfer coefficients are listed. Also listed are the average temperatures, existing at the start of the exothermic reaction in the spontaneous ignition process and at the moment of flaming ignition in the pilot ignition process. Values are given for each of the moisture contents examined for each of the various fuels tested. A minimum of 0.263 cal/cm^2/s produced spontaneous ignition in the Mill Creek Douglas-fir sample with 20.5 percent moisture content. A maximum of 0.327 cal/cm^2/s was necessary to produce spontaneous ignition in a ponderosa pine sample having an 18.2 percent moisture content. The minimum necessary to produce pilot ignition was 0.234 cal/cm^2/s for a ponderosa pine sample with 14.3 percent moisture content. The maximum necessary to produce pilot ignition was the 0.285 cal/cm^2/s required for a Douglas-fir sample with a 5.7 percent moisture content.

In appendix table 9 the total heat in cal/cm^2 and total calories necessary to produce ignition in the various fuel samples tested are listed. Values for both spontaneous and pilot ignition are given.

An average total of 14.7 calories was required to produce spontaneous ignition in the Blue Mountain Douglas-fir samples while the Mill Creek ponderosa pine required an average total of 23.6 calories. Pilot ignition was produced in the Elk Ridge ponderosa pine with an average total of only 10.1 calories while the Blue Mountain Douglas-fir required an average total of 22.0 calories--more that two times greater than the number of calories required for pilot ignition of the Elk Ridge ponderosa pine.

Density determinations had been made on the test samples. These determinations were examined in an attempt to explain the large differences in the heat required for ignition. The density of the Blue Mountain Douglas-fir samples was determined to be 0.332 as compared to the Mill Creek ponderosa pine density of 0.301. This difference in density was not deemed to be of sufficient magnitude to explain the difference in total heat required for ignition.

The difference in total heat required for pilot ignition also is not readily explained by density relations. The Elk Ridge ponderosa pine density was 0.247. The Douglas-fir Blue Mountain samples had a density of 0.332. The greater density material required more than twice the amount of heat for ignition, which is in contrast to the findings of Simms (1963).

The true effect of density on the ignition process in forest fuels is probably masked by a host of uncontrollable and unknown variables. Both the type and degree of decay can differ widely within the same piece of wood. For example, the density of the Mill Creek ponderosa pine sample-sections ranged from 0.234 to 0.457 and averaged 0.301; such a spread could easily mask any apparent differences among species. The presence of varied amounts of volatiles in individual test sections as well as among samples species also could mask the density difference relations.

CONCLUSIONS

The belief that rotten wood is one of the most easily ignitable fuels in the forest complex has been upheld by this study. Spontaneous ignition in an isothermal atmosphere occurred with temperatures as low as 260°C (500°F) for the Douglas-fir samples tested. Pilot ignition in the same fuel occurred with temperatures as low as 250°C (482°F).

A heat source capable of producing 0.358 cal/cm^2/s for 34 seconds may cause spontaneous ignition in Douglas-fir rotten wood having a moisture content near 24 percent. Samples with 6 percent moisture content may be ignited with a heat source capable of producing 0.325 cal/cm^2/s for only 22 seconds. Ponderosa pine rotten wood with 6 percent moisture content may be spontaneously ignited by a heat flux of 0.306 cal/cm^2/s of 13 seconds duration; samples with 23 percent moisture content required 0.402 cal/cm^2/s for 41 seconds. Subalpine fir rotten wood with a 6 percent moisture content ignited in 9 seconds when subjected to a heat flux of 0.358 cal/cm^2/s.

Pilot ignition of rotten wood occurred even more readily. A heat source capable of producing 0.287 cal/cm^2/s for only 16 seconds produces ignition in ponderosa pine samples having moisture content to 23 percent. Douglas-fir rotten wood will ignite with the same intensity heat source but requires 33 seconds.

The time to spontaneous ignition as related to moisture content was found to be significantly longer as moisture content of the samples increased beyond the 13 to 15 percent level. Significant difference was not found to exist for moisture contents of approximately 5 percent to 14 percent. The significance did not exist for the time to pilot ignition vs moisture content relation.

From the above the conclusion can be drawn that increasing moisture contents to 15 percent have negligible effect on spontaneous or pilot ignitions of rotten wood. Moisture contents greater than 15 percent to approximately 24 percent delay the time to spontaneous ignition but not for pilot ignition.

From this we can conclude that the probability of spontaneous ignition in rotten wood does not significantly decrease with increasing moisture contents to approximately 15 percent but will decrease for moisture contents from 15 percent to 24 percent, the highest level that was tested. The pilot ignition procedure for rotten wood as determin by the test procedures was not found to be significantly affected by moisture contents to 24 percent.

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APPENDIX

Table 1.--*Percentage of spontaneous ignitions of various rotten wood sections at selected furnace temperatures for 20 tests per moisture content*

Fuel sample	Moisture content	Furnace temperature								
		250	260	270	280	290	300	310	320	330
	Percent	- - -	- - -	- - -	- - -	°C	- - -	- - -	- - -	- - -
Ponderosa pine,	5.6						0	15	100	
Elk Ridge	14.3						0	35	100	
	22.8						0	20	100	
Ponderosa pine,	4.8		0	15	15	90	100			
Mill Creek	11.6		0	5	0	10	20	45	100	
	18.2			0	0	15	35	60	100	
Douglas-fir,	6.9		0	0	0	95	100			
Mill Creek	14.6	0	5	35	25	100				
	20.5		0	30	10	100				
Douglas-fir,	5.7			0	35	95	100			
Blue Mountain	13.8				0	70	100			
	23.7				0	75	100			
Subalpine fir,	6.0					0	5	40	45	100
Lolo Creek	13.4					0	10	40	60	100
	21.0					0	15	40	100	

Table 2.--*Time to spontaneous ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Start of exothermic reaction	Sharp rise in trace	Visual glowing	Furnace temperature
	Percent	- - - - - - -	*Seconds*	- - - - - -	°C
Ponderosa pine,	5.6	19.0	57.9	60.6	320
Elk Ridge	14.3	18.1	52.4	54.0	320
	22.8	20.0	59.5	62.9	320
Ponderosa pine,	4.8	12.9	36.8	40.8	300
Mill Creek	11.6	37.0	72.8	78.0	320
	18.2	41.1	62.4	67.9	320
Douglas-fir,	6.9	17.1	40.2	47.1	300
Mill Creek	14.6	33.8	53.5	59.6	290
	20.5	34.4	51.0	55.2	290
Douglas-fir,	5.7	21.9	43.6	50.0	300
Blue Mountain	13.8	25.2	43.9	48.2	300
	23.7	34.2	52.8	58.4	300
Subalpine fir,	6.0	9.1	36.7	38.8	330
Lolo Creek	13.4	18.4	42.6	46.4	330
	21.0	30.2	57.8	61.6	320

Table 3.--*Temperatures at time of spontaneous ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Start at exothermic reaction	Sharp rise in trace	Visual glowing	Furnace temperature
	Percent	- - - - - - - - -	- - - °C - - -	- - - - - - - - -	- - - - - - - - -
Ponderosa pine, Elk Ridge	5.6	280	320	333	320
	14.3	268	313	326	320
	22.8	279	316	332	320
Ponderosa pine, Mill Creek	4.8	250	286	313	300
	11.6	252	288	312	320
	18.2	287	315	338	320
Douglas-fir, Mill Creek	6.9	250	294	356	300
	14.6	250	267	300	290
	20.5	248	267	290	290
Douglas-fir, Blue Mountain	5.7	252	286	340	300
	13.8	256	287	325	300
	23.7	256	276	300	300
Subalpine fir, Lolo Creek	6.0	268	314	333	330
	13.4	282	307	325	330
	21.0	283	305	315	320

Table 4.--*Percentage of pilot ignitions of various rotten wood sections at selected furnace temperatures for 20 tests per moisture content*

Fuel sample	Moisture content	Furnace temperature			
		240	250	260	270
	Percent	- - - -	- - - °C	- - -	- - - -
Ponderosa pine, Elk Ridge	5.6		0	40	100
	14.3		0	20	100
	22.8		0	20	100
Douglas-fir, Blue Mountain	5.7		0	90	100
	13.8	0	5	60	100
	23.7	0	5	65	100

Table 5.--*Time to pilot ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Time to flaming ignition	Furnace temperatures
	Percent	*Seconds*	°C
Ponderosa pine, Elk Ridge	5.6	14.2	270
	14.3	16.1	270
	22.8	13.0	270
Douglas-fir, Blue Mountain	5.7	26.8	270
	13.8	33.1	270
	23.7	29.2	270

Table 6.--*Temperatures at time of pilot ignition of various rotten wood sections at various moisture contents--100 percent of all samples igniting*

Fuel sample	Moisture content	Temperature of ignition	Furnace temperature
	Percent	°C	°C
Ponderosa pine, Elk Ridge	5.6	241	270
	14.3	233	270
	22.8	237	270
Douglas-fir, Blue Mountain	5.7	278	270
	13.8	267	270
	23.7	255	270

Table 7.--*Average heat flux and temperature at initiation of exothermic reaction during spontaneous ignition of rotten wood sections--100 percent ignition of all samples*

Fuel sample	Moisture content	Heat flux	Start of exothermic reaction	Furnace temperature
	Percent	*Cal/cm^2/s*	°C	°C
Ponderosa pine, Elk Ridge	5.6	0.318	280	320
	14.3	.303	268	320
	22.8	.316	279	320
Ponderosa pine, Mill Creek	4.8	.266	250	300
	11.6	.283	252	320
	18.2	.327	287	320
Douglas-fir, Mill Creek	6.9	.266	250	300
	14.6	.266	250	300
	20.5	.264	248	290
Douglas-fir, Blue Mountain	5.7	.268	252	300
	13.8	.268	252	300
	23.7	.273	256	300
Subalpine fir, Lolo Creek	6.0	.308	268	330
	13.4	.326	282	330
	21.0	.322	283	320

Table 8.--*Average heat flux and temperature at flaming ignition during pilot ignition of rotten wood sections--100 percent of all samples igniting*

Fuel sample	Moisture content	Heat flux	Flaming ignition	Furnace temperature
	Percent	*Cal/cm²/s*	- - - - - *°C* - - - - - -	
Ponderosa pine,	5.6	0.243	241	270
Elk Ridge	14.3	.234	233	270
	22.8	.238	237	270
Douglas-fir,	5.7	.285	278	270
Blue Mountain	13.8	.272	267	270
	23.7	.258	255	270

Table 9.--*Average total heat needed to produce spontaneous and pilot ignition in various rotten wood sections--all ignitions included*

Fuel sample	Type of ignition	Total heat required for ignition	
		Cal/cm²	*Calories*
Ponderosa pine, Elk Ridge	Spontaneous	5.5	14.9
Ponderosa pine, Mill Creek	Spontaneous	8.8	23.6
Douglas-fir, Mill Creek	Spontaneous	7.4	17.0
Douglas-fir, Blue Mountain	Spontaneous	6.4	14.7
Subalpine fir, Lolo Creek	Spontaneous	5.6	15.0
Ponderosa pine, Elk Ridge	Pilot	3.8	10.1
Douglas-fir, Blue Mountain	Pilot	9.6	22.0

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FIRE CONTAINMENT EQUATIONS FOR POCKET CALCULATORS

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ABSTRACT

Presents simplified equations for solving the fire containment problem. Equations can be used on a programmable pocket calculator to derive the burned area, given forward rate of spread, initial area, fire shape length/width ratio, and control-line construction rate. Equations can also be used to find the line construction rate needed to hold the burned area to a fixed value, knowing the other variables listed. Potential uses seen for this capability are preliminary fire control planning and as a dispatching aid. Copies of a program for the Texas Instruments Model 59 calculator[2] are available on request.

KEYWORDS: Fire containment, fire control, fire suppression, planning, dispatching, calculator program

Prefire planning and initial attack dispatching are fire management activities that require the solution to the classical fire containment problem: How much containment capability is needed? The question can be phrased in a variety of ways and answered in many ways. Often there are additional considerations that modify or even override the answer to the strictly-limited question, but it is still necessary to estimate potential fire sizes and potential requirements for fire suppression capabilities (Barrows 1951).

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

Concern over rising costs of wildland fire suppression has stimulated more intensive planning for fire control.[3] The computer program FOCUS (Storey 1972) was designed to test fire control plans and force dispositions for the purpose of increasing efficiency and reducing costs. This program uses tables of numbers that give the final area and perimeter of an easily controlled fire in terms of its initial area, length/width ratio, and ratio of control line construction rate to forward rate of spread (Bratten 1978).

For preliminary planning work and as a ready aid for dispatcher use, a simplified mechanized process for solving the fire containment problem may be useful. This note presents simple equations that can be used on a programmable pocket calculator for this purpose. The structure of an appropriate program for such application is given. This structure has been used to program a Texas Instrument Model 59 calculator to solve the equations presented here.

SIMPLIFYING ASSUMPTIONS

In its general (real-life) form, the mathematical problem of calculating the time required to construct a control line around a spreading fire, working at the fire edge, is intractably complicated. By making a series of simplifying assumptions, the problem can be reduced to one that can be solved. The applicability of the results must then be judged according to how closely the real situation conforms to the idealized model of it. So that the reader may make such judgment, the assumptions used in setting up the mathematical problem are spelled out below:

1. The unconstrained spread of the fire would not change its shape. That is, while the fire may spread at different rates in different directions, its growth would resemble the enlargement of a photograph.

2. The rate of spread of the fire is constant over the time that control line construction takes place. In practical terms this implies that the fire is contained within one burning period and that the fuels, topography, and weather remain essentially the same from the time work starts until it is finished.

3. The shape of the free-burning fire is that of an ellipse, with the point of origin at a focus. Of course it need not be exactly an ellipse, but an elliptical shape must roughly describe the location of the fire edge. Note that an ellipse with a length/width ratio of unity is a circle, so this case is included. See figure 1 for ellipses of various length/width (L/W) ratios.

4. The rate of line construction is constant. Of course this is never exactly correct, but the analysis depends on treating the rate as a constant. By using different, constant, values in example calculations, one can explore how sensitive the results are to the validity of this assumption in each case considered.

5. Work proceeds simultaneously on both sides of the fire at an equal pace. That is, the line-construction force is split into two equal parts (in terms of line construction rates) and they separate at the point of attack--either the head or the rear of the fire--and work around the flanks to meet at the opposite end.

6. The containment line is constructed at the edge of the fire. No indirect containment tactics are handled in this simplified analysis, so this constraint indirectly limits the intensity level of fires that can be analyzed; only fires of low and moderate intensity permit direct suppression (Albini 1976).

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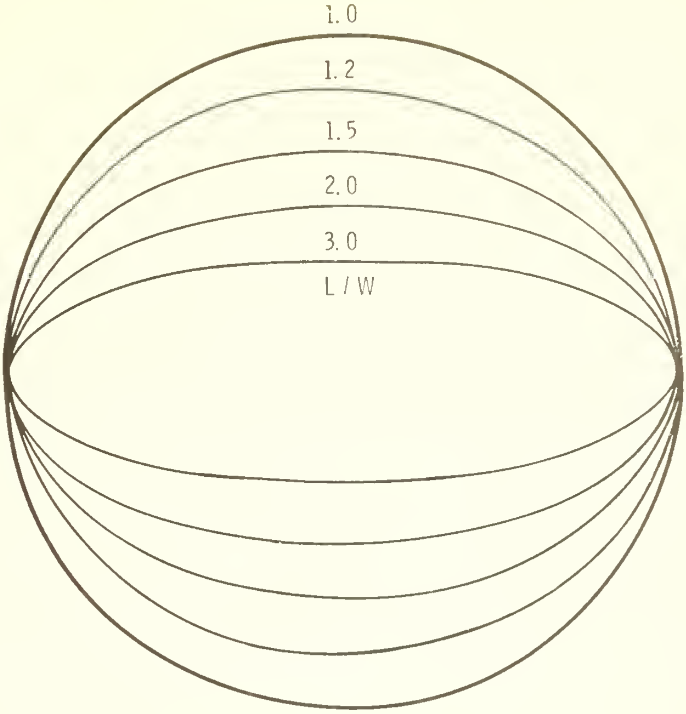
[3] "Fire management analysis for forest planning," National Fire Management Planning Task Force, USDA For. Serv. Working Draft No. 1; May 1979 (to be revised). Authors: James F. Mann, Richard A. Henry, Richard A. Chase, Randall J. Van Gelder.

Figure 1.--Ellipses of various length/width (L/W) ratios.



The last constraint is imposed simply to limit the scope of the cases considered. Indirect attack tactics have been successfully treated (Albini and others 1978) so the methodology could be extended if interest warrants it. That is, we could fit curves to numerical results obtained using a well-placed barrier before the head of the fire as done by Albini and others (1978).

7. An implicit assumption here is that the containment or suppression work is 100 percent effective. That is, the fire does not spread beyond the control line once constructed.

METHODOLOGY

The problem described above, with the simplifying assumptions outlined, was formulated mathematically and reduced to the numerical evaluation of two integrals (Albini and others 1978). The exact expressions to be computed are:

$$P/2R(\theta_o) = \int_{\theta_o}^{\theta_o+\pi} G(\theta)F(\theta)d\theta \qquad (1)$$

$$A/R^2(\theta_o) = \int_{\theta_o}^{\theta_o+\pi} F^2(\theta)d\theta \qquad (2)$$

where

P = the final perimeter of the burned area (= the total length of control line constructed)

A = the burned area

$R(\theta_o)$ = the distance from the fire's point of origin to the point on its edge where control line construction started, designated by the angle θ_o.

The function F describes the shape of the final burned area in radial coordinates,[4] and the product GF is the derivative of perimeter length with respect to the angle θ. The size and shape of the free-burning fire is described in radial coordinates, with origin at the point of origin of the fire, by the function $r(\theta,t)$, where

$r(\theta,t)$ = distance from the point of origin to the fire edge at time t in the direction θ
θ = an angle measured from the direction of the maximum rate of spread ($\theta = 0$ toward the head of the fire), counterclockwise
t = time since start of the fire.

In terms of the function r, its time derivative $\dot{r}$, its derivative with respect to the angle r', and rate of control line construction on each flank, V_L, the function F can be written as

$$F(\theta) = \exp\left(\int_{\theta_o}^{\theta} f(\theta')d\theta'\right) \tag{3}$$

where

$$f = \frac{\dot{r}/V_L + (r'/r)\left(1 + (r'/r)^2 - (\dot{r}/V_L)^2\right)^{1/2}}{-(r'/r)(\dot{r}/V_L) + \left(1 + (r'/r)^2 - (\dot{r}/V_L)^2\right)^{1/2}}. \tag{4}$$

Because of simplifying assumptions 1, 2, and 4, the function f is independent of time. Likewise, function $G(\theta)$ is time-independent:

$$G = \left(1 + (r'/r)^2\right)/\left(- (r'/r)(\dot{r}/V_L) + \left(1 + (r'/r)^2 - (\dot{r}/V_L)^2\right)^{1/2}\right). \tag{5}$$

By assumption 3 above the outline of the free-burning fire can be expressed as

$$r(\theta) = r(0)(1 - \varepsilon)/(1 - \varepsilon \cos \theta) \tag{6}$$

where $r(0)$, the distance from the point of origin to the head of the fire is given by

$$r(0) = V_F t \tag{7}$$

and V_F is the forward rate of spread. The factor ε in equation 6 is the eccentricity of the elliptical fire outline. It is related to the length/width ratio, L/W, by the formula

$$\varepsilon = \left((L/W)^2 - 1\right)^{1/2}/(L/W). \tag{8}$$

If control line construction starts at the head of the fire, θ_o is zero; if at the rear, θ_o is π:

$$R(\theta_o) = \begin{cases} r(0), & \theta_o = 0 \\ r(0)(1 - \varepsilon)/(1 + \varepsilon), & \theta_o = \pi \end{cases} \tag{9}$$

The value of $r(0)$ can be related to the area of the fire at the time line construction begins, A_o, and the length/width ratio:

$$r(0) = (1 + \varepsilon)\left((L/W)A_o/\pi\right)^{1/2}. \tag{10}$$

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[4] The interested reader should consult Albini and others (1978) for the development of equations 1-5. These equations are given here only for completeness of this presentation.

APPROXIMATE FORMS

The equations above were programmed for calculation on the CDC7600 computer at Lawrence Berkeley Laboratories' facility on the University of California campus at Berkeley. The results, expressed in the dimensionless forms of equations 1 and 2, were tabulated against the ratios V_F/V_L and L/W. The tabular entries were then fitted by simple functional forms.

Holding L/W constant, nonlinear regressions yielded functions of V_F/V_L. Keeping the functional forms constant allowed the tabulation of the regression coefficients in terms of the fire shape parameter L/W. These tables were, in turn, fitted to simple forms by regressions. The expressions resulting from this sequence are listed in the equation summary below.

The approximate forms for elliptical fire shapes are accurate to within about 5 percent for all length/width ratios in the range 1.2 to 3.0 inclusive. Outside this range the expressions begin to deviate rapidly from "exact" results. The upper limit of 3.0 is probably not overly restrictive, because fires with greater eccentricity than this will probably not be contained on initial attack or within one burning period (recall assumptions 1 and 2 above). This is so because usually only very rapidly spreading fires will have large length/width ratios.

Because the fire shape used here is an ellipse and the point of origin of the fire is at a focus of the ellipse, a length/width ratio of 3.0 represents a fire spreading very much more rapidly in the forward direction than in the backing direction. The graph in figure 2 shows how the length/width ratio varies with the ratio of forward to backing rates of spread.[5] From this figure one can see that a fire with length/width ratio exceeding 3.0 would probably escape initial attack. Figure 3 shows the variation of length/width ratio with windspeed, based on Hal Anderson's double-ellipse formulas for wind-driven fire shapes (Albini 1976, erratum). This graph indicates that the windspeed at 20-foot height must exceed 20 mi/h before a length/width ratio of 3 is exceeded.

To extend the lower limit (L/W = 1.2), exact results for a circular fire shape are used. When the unconstrained fire grows as a circle, functions f (equation 4) and G (equation 5) become constants and equations 1 and 2 are simple to evaluate. These results are listed in the summary of equations. Whenever the length/width ratio of an elliptical fire shape is less than 1.2, the circular fire shape results can be used to obtain approximate results.

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[5] The spread rate ratio is the ratio of distance from the focus of origin to the forward and backward edges of the ellipse.

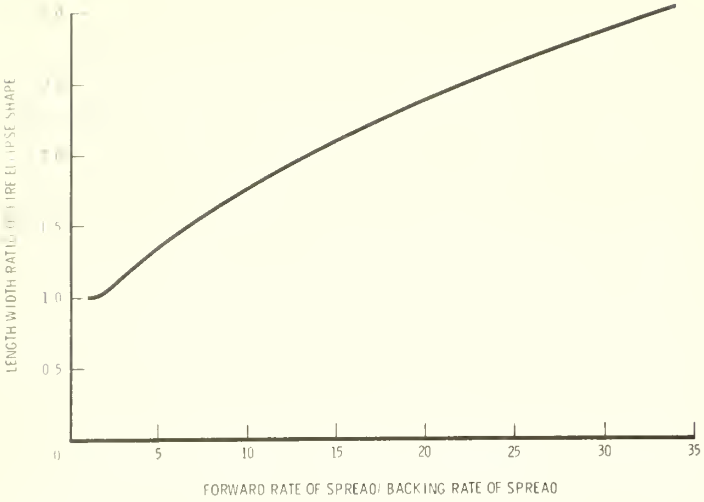

Figure 2.--Variation of length/width ratio of elliptical fire shapes with the ratio of forward rate of spread to backing rate of spread.

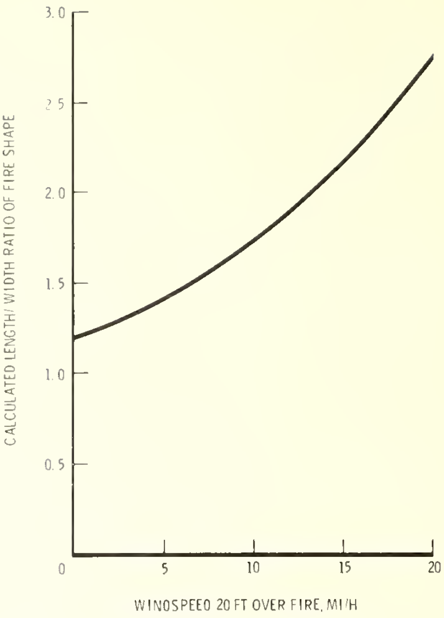

Figure 3.--Calculated length/ width ratios for fire shapes, based on Hal Anderson's double-ellipse equations.

SUMMARY OF EQUATIONS FOR FIRE CONTAINMENT

Symbols

A_o = area of fire at the time containment work begins

$r(0)$ = distance from point of origin to head of fire when containment work begins

L/W = length/width ratio of elliptical shape of free-burning fire

V_F = forward rate of spread of free-burning fire

V_L = rate of construction of control line on each flank

A_B = final area of contained fire

P = perimeter of burned area (= length of control line built)

Δt = elapsed time to contain the fire

All Cases

$$r(0) = (1 + \varepsilon)\left((L/W)A_o/\pi\right)^{1/2}$$

$$\varepsilon = \left((L/W)^2 - 1\right)^{1/2}/(L/W)$$

$$\Delta t = P/(2V_L)$$

Case A. Work Starts at Head of Fire ($1.2 \le L/W \le 3.0$)

$$P/A_B^{1/2} = 3.52 + 0.044(L/W)^{2.4}$$

$$A_B^{1/2}/r(0) = \begin{cases} A_{11} + A_{12}(V_F/V_L)^{A_{13}}, & 0 \le V_F/V_L \le 0.95 \\ A_{21} + A_{22}\left(-\frac{1}{3}\ln(1 - V_F/V_L)\right)^{A_{23}}, & 0.95 < V_F/V_L < 1 \end{cases}$$

$$A_{11} = \left(2.341 - 3.126\exp(-0.6284\ L/W)\right)^{-1}$$

$$A_{12} = \left(4.799(L/W)^{0.774} - 5.047\right)^{-1}$$

$$A_{13} = \left(1.02 - 1.62\exp(-0.82\ L/W)\right)^{-1}$$

$$A_{21} = 0.45 + 2/(L/W)^3$$

$$A_{22} = 0.55(L/W - 1) - 2/(L/W)^3$$

$$A_{23} = 0.091 + 1.76/(L/W)^2$$

Case B. Work Starts at Back of Fire ($1.2 \le L/W \le 3.0$)

$$r(0)/A_B^{1/2} = B_{11} + B_{12}(V_F/V_L)^{B_{13}}$$

$$P/2r(0) = \left(B_{21}/(1.0 - V_F/V_L)\right)^{B_{22}}$$

$$B_{11} = 0.825 + 0.925\left(\ln\ (L/W)\right)^{1.01}$$

$$B_{12} = 5.1 - 5.96(L/W)^{0.1234}$$

$$B_{13} = -0.813 + 1.972\left(\ln\ (L/W)\right)^{0.0925}$$

$$B_{21} = 1.112 + 3.4\exp(-1.5L/W)$$

$$B_{22} = \left(0.988 - 2.46\exp(-2.35L/W)\right)^{-1}$$

Case C. Circular Fire Shape ($1 \le L/W < 1.2$)

$$A_B/A_o = \left(\exp(Z) - 1\right)/Z$$

$$P/2r(0) = \left(\exp(Z/2) - 1\right)(V_F/V_L)$$

$$Z = 2\pi/\left((V_F/V_L)^2 - 1\right)^{1/2}$$

The equations given in the summary can be inverted to express the rate of line construction required (V_L) to keep the burned area (A_B) to a specified value. In the pocket calculator program structure shown below, this option is selectable.

In the circular fire case, the equation for A_B/A_o in terms of Z can be solved for Z using the iteration:

$$Z_1 = 2 \ln (A_B/A_o) \quad (11)$$

$$Z_{n+1} = \left(1 + (Z_n - 1)\exp(Z_n)\right)/\left(\exp(Z_n) - A_B/A_o\right). \quad (12)$$

That is, use equation (11) to calculate a first estimate (Z_1) for Z, and use equation (12) to calculate successively better approximations Z_2, Z_3, etc., using the last estimate (Z_n) to generate the next one (Z_{n+1}). Repeating equation (12) six times gives convergence of Z to within one percent for A_B/A_o of 1,000. The iteration is strongly convergent.

Note that all the equations given in the summary are in dimensionless form. That is, the burned area is always divided by the initial area or appears as the square root divided by r(0); V_F and V_L always appear in ratio, etc. This was done for the convenience of the user, so that any system of units could be used. While the choice of units is up to the user, the user is reminded that internal consistency demands that the square of the unit of length be the unit of area. So if one chooses to express rate of spread and line construction rate in chains per hour, the unit of area (initial area and burned area) is squared chains. In this case it would be necessary to multiply areas measured in acres by a factor of 10 to convert them to squared chains. If the rate units are feet per minute (or per second or per hour) the area units are square feet, etc.

The conversion factor desired can be included in the program for a pocket calculator; this was done for a version programmed at the Northern Forest Fire Laboratory. In this version (see appendix), the units are assumed to be chains per hour and acres, the most common American forestry units, so a factor of 10 was programmed to multiply area entries to convert them to squared chains internally. For display, calculated areas are converted to acres. In the list of symbols shown in the appendix, the initial area in squared chains is denoted by A_o* while the same area in acres is called A_o. The asterisk implies the same conversion for burned area, A_B.

CALCULATOR PROGRAM STRUCTURE

The equations listed in the summary can be solved using a programmable pocket calculator. Exhibits 1 and 2 show appropriate program structures for the elliptical and circular fire shapes, respectively. These structures have been used to program the Texas Instruments Model 59 calculator. The combined cases A and B fit within the storage capability of that calculator, and required two magnetic-strip cards to record. Case C is much more compact, but could not be combined with either case A or B, so was recorded separately. Copies of these programs on magnetic strips are available from the authors at the Northern Forest Fire Laboratory. See the appendix for program listings and instructions for using them.

OPERATING STEPS, ELLIPTICAL FIRE SHAPE PROGRAM

1. Select case: A = head attack; B = rear attack
2. Select option: A' = compute line construction rate; B' = compute burned area
3. Input V_F
4. Input A_o
5. A': Input A_B (stop occurs if $A_B \leq A_o$)
   -or-
   B': Input V_L (stop occurs if $V_L \leq V_F$)
6. Input L/W (stop occurs if out of range)

Computation Sequence

1. Test: $1.2 \leq L/W \leq 3.0$ (stop out of range)

2. Calculate: ε, $r(0)$

3. Case A. Calculate and store A_{ij} coefficients

   Option A'. Test: $A_B/A_o > 1.0$ (stop out of range)

   Test: $A_B^{1/2}/r(0) < A_{21} + A_{22}$ (choose equation for V_L)

   Calculate: V_L, P, Δt

   Option B'. Test: $V_F/V_L > 1.0$ (stop out of range)

   Test: $V_F/V_L \leq 0.95$ (choose equation for V_L)

   Calculate: A_B, P, Δt

   Case B. Calculate and store B_{ij} coefficients

   Option A'. Test: $A_B/A_o > 1.0$ (stop out of range)

   Calculate: V_L, P, Δt

   Option B'. Test: $V_F/V_L < 1.0$ (stop out of range)

   Calculate: A_B, P, Δt

4. Display results

   Option A'. V_L, P, Δt

   Option B'. A_B, P, Δt

Exhibit 1.--Pocket calculator program structure and operating steps for solving the fire containment problem for elliptical fire shapes.

OPERATING STEPS, CIRCULAR FIRE SHAPE PROGRAM

1. Select option: A' = compute line construction rate; B' = compute burned area.
2. Input V_F
3. Input A_o
4. A': Input A_B (stop occurs if $A_B \leq A_o$)
   -or-
   B': Input V_L (stop occurs if $V_L \leq V_F$)

Computation Sequence

1. *Option A'.* Test: $A_B/A_o > 1.0$ (stop out of range)

   Calculate: Z, A_B, P, Δt

   Option B'. Test: $V_F/V_L < 1.0$ (stop out of range)

   Calculate: Z, V_L, P, Δt

2. Display results:

   Option A'. V_L, P, Δt

   Option B'. A_B, P, Δt

Exhibit 2.--Pocket calculator program structure and operating steps for solving the fire containment problem for circular fire shapes.

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APPENDIX: OPERATING PROCEDURE FOR SOLVING FIRE CONTAINMENT PROBLEMS ON THE TI-59 CALCULATOR

I. Preliminaries

1. Turn calculator on.
2. Press: 2 2nd Op 1 7 .

II. Selection of program

1. Press: 2nd CP INV 2nd Fix .
2. Select set of cards to be used (see fig. 1 to help you select the right value for L/W).
   - a. If L/W ≥ 1.2, use elliptical program, a set of 2 cards with sides 1 through 4.
   - b. If L/W < 1.2, use circular program, a single card with sides 1 and 2.
3. Press: 1 .
4. Feed into lower slot side 1 of program strip of option chosen (circular or elliptical). The motor will start and stop automatically. A 1. should appear in the display after the strip is read. If the display flashes, press CLR and go back to step 3.
5. Press: 2 .
6. Feed in side 2 of program strip. (Keep printed side up, just start at the other end.) A 2. should appear in the display after the strip is read. If the display flashes, press CLR and go back to step 5.
7. (OMIT STEPS 7-10 FOR CIRCULAR OPTION.) Press: 3 .
8. Feed in side 3 similarly. The number 3. should appear in the display. If the display flashes, go back to step 7.
9. Press: 4 .
10. Feed in side 4 as above. When the number 4. appears in the display, you are ready to solve the problem. If the display flashes, press CLR and go back to step 9.

III. (OMIT PART III FOR CIRCULAR OPTION.)
Select mode of attack on fire

1. If containment work is to begin at the *head* of the fire, press A .
2. If containment work is to begin at the *rear* of the fire, press B .

Each time a problem is solved, one *must* select either A or B. If A or B is pressed in the circular option, a flashing display will result. Press CLR and proceed.

IV. Choose type of problem to be solved.

1. To calculate line building rate required to hold burned area to a set acreage, press 2nd A' .
2. To calculate burned area when fire is contained with a set line building rate, press 2nd B' .

Each time a problem is solved, one *must* select either A' or B'.

A' Selected

1. Input forward rate of spread of fire in chains per hour. Press number keys (include decimal point if needed) and value will appear in the display. If an error is made, press CE and try again. When the desired number appears in the display, press R/S .

2. Input size of fire when containment work begins, in acres. When the desired number appears in the display, press $\boxed{\text{R/S}}$.
3. Input burned area target, in acres; press $\boxed{\text{R/S}}$. This value must be greater than the initial size or the display will flash 9's--go back to IV.
4. (OMIT STEP 4 IN CIRCULAR OPTION.) Input the length/width ratio of the fire shape at the time containment work begins. This number must be at least 1.2 and no more than 3.0. Press $\boxed{\text{R/S}}$. If L/W is outside the allowable range, display will flash 9's--go back to IV. If $1 \leq L/W < 1.2$, display will flash 1--go back to II and use circular option.
5. A flickering "C" should now appear in the display. If it does not, an error has occurred. Go back to III.
6. Calculation will cease with a number in the display. This number indicates the line-building rate (chains per hour) required on each flank of the fire. The total line-building rate capability, then, must be twice this number. Record this value for reference and then press $\boxed{\text{R/S}}$.
7. The number in the display indicates perimeter of the burned area (in chains) which is the same as the total length of control line constructed. Record this number for reference and then press $\boxed{\text{R/S}}$.
8. The number in the display indicates the time (in hours) that it will take to contain the fire. This completes the problem. To do another problem under the same option, go back to step III. To change options, go to part II.

B' Selected

I. Input forward rate of spread of fire in chains per hour. Press number keys (include decimal point if needed) and value will appear in display. If an error is made, press $\boxed{\text{CE}}$ and try again. When desired number appears in the display, press $\boxed{\text{R/S}}$.
2. Input size of fire when containment work begins, in acres. When the desired number appears in the display, press $\boxed{\text{R/S}}$.
3. Input line-building rate capability (chains per hour) assigned equally to each flank of the fire. Press $\boxed{\text{R/S}}$. This must be more than the forward rate of spread or the display will flash 9's--go back to IV.
4. (OMIT STEP 4 IN CIRCULAR OPTION.) Input the length/width ratio of the fire shape at the time containment work begins. This number must be at least 1.2 and no more than 3.0. Press $\boxed{\text{R/S}}$. If L/W is outside the allowable range, display will flash 9's--go back to IV. If $1.0 \leq L/W < 1.2$, display will flash 1--go back to II and use circular option.
5. A flickering "C" should now appear in the display. If it does not, an error has occurred. Go back to III.
6. Calculation will cease with a number in the display. This number is the burned area, in acres, when the fire is contained. Record this value for reference and then press $\boxed{\text{R/S}}$.
7. The number in the display now is the perimeter of the burned area, which is the same as the total length of control line constructed, in chains. Record this number for reference and then press $\boxed{\text{R/S}}$.
8. The number in the display now will be the time, in hours, that it will take to contain the fire. This completes the problem. To do another problem under the same option, go back to step III. To change options, go to part II.

Condensed Instruction Steps

I. Press 2 2nd Op 1 7 .

II. Press 2nd CP INV 2nd Fix .

Load: Press 1 , feed side 1, display 1. (flashing display: CLR try again)
Press 2 , feed side 2, display 2. (flashing display: CLR try again)
Etc.

III. Mode of attack--head: A } OMIT FOR CIRCULAR OPTION--Flashing display, CLR ,
Mode of attack--rear: B } continue

IV. Calculate line building rate: 2nd A'
Calculate burned area: 2nd B'

Option A'

Input

1. Forward rate of spread (ch/h), R/S
2. Initial fire size (acres), R/S
3. Burned area target (acres), R/S
4. Length/width ratio (1.2 - 3), R/S

Output

5. Line building rate per flank (ch/h): R/S
6. Total length of line (ch): R/S
7. Containment time (hours)

Error Indications

(3) Flashing 9's--number too small--go to IV
(4) a. Flashing 9's--number out of range--go to IV
    b. Flashing 1--wrong option--go to II and use circular option

Option B'

Input

1. Forward rate of spread (ch/h), R/S
2. Initial fire size (acres), R/S
3. Line building rate per flank (ch/h), R/S
4. Length/width ratio (1.2 - 3) R/S

Output

5. Burned area (acres): R/S
6. Total length of line (ch): R/S
7. Containment time (hours)

Error Indications

(3) Flashing 9's--number too small--go to IV
(4) a. Flashing 9's--number out of range--go to IV
    b. Flashing 1--wrong option--go to II and use circular option

Worked Examples

1. Suppose a fire has a size of 2 acres, a forward rate of spread of 15 chains per hour, and a length/width ratio of 2.5 when line construction begins. Assuming attack at the head of the fire, what line construction capability is required to contain the fire at 4 acres?

Step	Procedure	Enter	Display should be	Press	Display changes to
I.1	Turn calculator on				
I.2	Partition program memory			2 2nd Op 1 7	799.19
II.1	Clear memory; prepare decimal format			2nd CP INV 2nd Fix	ignore
II.2	Select elliptical program				
II.3	Prepare to read side 1	1	1		
II.4	Insert program side 1	(motor starts & stops automatically)			1.
II.5	Prepare to read side 2	2	2		
II.6	Insert program side 2	(motor starts & stops automatically)			2.
II.7	Prepare to read side 3	3	3		
II.8	Insert program side 3	(motor starts & stops automatically)			3.
II.9	Prepare to read side 4	4	4		
II.10	Insert program side 4	(motor starts & stops automatically)			4.
III.1	Select head attack			A	ignore
IV.1	Select calculation of line building rate			2nd A'	ignore
A'.1	Enter rate of spread	15	15	R/S	15.
A'.2	Enter size when fire containment begins	2	2	R/S	2.
A'.3	Enter burned area target	4	4	R/S	4.
A'.4	Enter length/width ratio	2.5	2.5	R/S	flickering C
A'.6	Record line construction rate on each flank (ch/h)				15.5 ←
A'.7	Record perimeter of		15.5	R/S	24.8 ←
A'.8	Record time required to contain fire (hours)		24.8	R/S	0.8 ←

Output: 15.5 = line construction rate on each flank (ch/h)
24.8 = perimeter of burned area (ch)
0.8 = time required to contain fire (hours)

2. Suppose that the size of a fire is 2 acres when containment begins and that the forward spread rate is 15 chains per hour. If the length/width ratio is 1 and line can be constructed at a rate of 25 chains per hour on each flank, what is the burned area when the fire is contained?

Step	Enter	Press	Display
II		2nd CP INV 2nd Fix	ignore
	1	(insert side 1)	1.
	2	(insert side 2)	2.
IV		2nd B'	ignore
	15	R/S	15.
	2	R/S	2.
	25	R/S	46.8 ←
		R/S	80.3 ←
		R/S	1.6 ←

Output: 46.8 = burned area (acres)
80.3 = perimeter of burned area (ch)
1.6 = time required to contain fire (hours)

Storage Registers

Register number	Elliptical shape	Circular shape
00	V_F	V_F
01	A_o	A_o
02	A_B	A_B
03	L/W	L/W
04	V_L	V_L
05	P	P
06	Δt	Δt
07	A_{11}, B_{11}	
08	A_{12}, B_{12}	
09	A_{13}, B_{13}	
10	B_{22}	
11	B_{23}	
12	$A_o{}^*$	$A_o{}^*$
13	$A_B{}^*$	$A_B{}^*$
14	V_F/V_L	V_F/V_L
15	A_{21}	
16	A_{22}	
17	A_{23}	
18	r(0)	r(0)
19		Z

ELLIPTICAL
FIRE SHAPE

```
000  76 LBL
001  11  A
002  22 INV
003  58 FIX
004  22 INV
005  86 STF
006  01  01
007  22 INV
008  86 STF
009  02  02
010  47 CMS
011  91 R/S
012  76 LBL
013  12  B
014  22 INV
015  58 FIX
016  22 INV
017  86 STF
018  02  02
019  86 STF
020  01  01
021  47 CMS
022  91 R/S
023  76 LBL
024  16 A'
025  91 R/S
026  42 STO
027  00  00
028  91 R/S
029  42 STO
030  01  01
031  32 X:T
032  43 RCL
033  01  01
034  91 R/S
035  42 STO
036  02  02
037  22 INV
038  77  GE
039  52 EE
040  67  EQ
041  52 EE
042  43 RCL
043  02  02
044  91 R/S
045  61 GTO
046  24 CE
047  76 LBL
048  17 B'
049  86 STF
050  02  02
051  91 R/S
052  42 STO
053  00  00
054  32 X:T
055  43 RCL
056  00  00
057  91 R/S
058  42 STO
059  01  01
060  91 R/S
061  42 STO
062  04  04
063  22 INV
064  77  GE
065  52 EE
066  67  EQ
067  52 EE
068  91 R/S
069  76 LBL
070  24 CE
071  42 STO
072  03  03
073  32 X:T
074  01  1
075  32 X:T
076  22 INV
077  77  GE
078  52 EE
079  32 X:T
080  03  3
081  22 INV

082  77  GE
083  52 EE
084  01  1
085  93  .
086  02  2
087  32 X:T
088  43 RCL
089  03  03
090  22 INV
091  77  GE
092  44 SUM
093  53  (
094  53  (
095  43 RCL
096  03  03
097  65  ×
098  93  .
099  06  6
100  02  2
101  08  8
102  04  4
103  54  )
104  94 +/-
105  22 INV
106  23 LNX
107  65  ×
108  02  2
109  93  .
110  01  1
111  02  2
112  06  6
113  94 +/-
114  85  +
115  02  2
116  93  .
117  03  3
118  04  4
119  01  1
120  54  )
121  35 1/X
122  42 STO
123  07  07
124  53  (
125  43 RCL
126  03  03
127  45 Yˣ
128  93  .
129  07  7
130  07  7
131  04  4
132  65  ×
133  04  4
134  93  .
135  07  7
136  09  9
137  09  9
138  75  -
139  05  5
140  93  .
141  00  0
142  04  4
143  07  7
144  54  )
145  35 1/X
146  42 STO
147  08  08
148  53  (
149  53  (
150  43 RCL
151  03  03
152  65  ×
153  93  .
154  08  8
155  02  2
156  94 +/-
157  54  )
158  22 INV
159  23 LNX
160  65  ×
161  01  1
162  93  .
163  06  6
164  02  2
165  94 +/-
166  85  +
167  01  1

168  93  .
169  00  0
170  02  2
171  54  )
172  35 1/X
173  42 STO
174  09  09
175  53  (
176  53  (
177  43 RCL
178  03  03
179  45 Yˣ
180  03  3
181  54  )
182  35 1/X
183  65  ×
184  02  2
185  54  )
186  42 STO
187  19  19
188  85  +
189  93  .
190  04  4
191  05  5
192  95  =
193  42 STO
194  15  15
195  43 RCL
196  19  19
197  94 +/-
198  85  +
199  53  (
200  93  .
201  05  5
202  05  5
203  55  ÷
204  53  (
205  43 RCL
206  03  03
207  75  -
208  01  1
209  54  )
210  54  )
211  95  =
212  42 STO
213  16  16
214  43 RCL
215  03  03
216  33 X²
217  35 1/X
218  65  ×
219  01  1
220  93  .
221  07  7
222  06  6
223  85  +
224  93  .
225  00  0
226  09  9
227  01  1
228  95  =
229  42 STO
230  17  17
231  43 RCL
232  01  01
233  65  ×
234  01  1
235  00  0
236  95  =
237  42 STO
238  12  12
239  43 RCL
240  02  02
241  65  ×
242  01  1
243  00  0
244  95  =
245  42 STO
246  13  13
247  53  (
248  53  (
249  43 RCL
250  03  03
251  33 X²
252  35 1/X
253  94 +/-

254  85  +
255  01  1
256  54  )
257  34 √X
258  85  +
259  01  1
260  54  )
261  65  ×
262  53  (
263  43 RCL
264  03  03
265  65  ×
266  43 RCL
267  12  12
268  55  ÷
269  89  π
270  54  )
271  34 √X
272  95  =
273  42 STO
274  18  18
275  87 IFF
276  02  02
277  22 INV
278  87 IFF
279  01  01
280  42 STO
281  43 RCL
282  18  18
283  35 1/X
284  65  ×
285  43 RCL
286  13  13
287  34 √X
288  95  =
289  32 X:T
290  43 RCL
291  15  15
292  85  +
293  43 RCL
294  16  16
295  95  =
296  22 INV
297  77  GE
298  33 X²
299  76 LBL
300  32 X:T
301  53  (
302  53  (
303  53  (
304  43 RCL
305  13  13
306  34 √X
307  55  ÷
308  43 RCL
309  18  18
310  75  -
311  43 RCL
312  07  07
313  54  )
314  55  ÷
315  43 RCL
316  08  08
317  54  )
318  22 INV
319  45 Yˣ
320  43 RCL
321  09  09
322  54  )
323  35 1/X
324  65  ×
325  43 RCL
326  00  00
327  95  =
328  42 STO
329  04  04
330  87 IFF
331  01  01
332  45 Yˣ
333  76 LBL
334  23 LNX
335  53  (
336  43 RCL
337  03  03
338  45 Yˣ
339  02  2

340  93  .
341  04  4
342  65  ×
343  93  .
344  00  0
345  04  4
346  04  4
347  85  +
348  03  3
349  93  .
350  05  5
351  02  2
352  54  )
353  65  ×
354  43 RCL
355  13  13
356  34 √X
357  95  =
358  42 STO
359  05  05
360  76 LBL
361  35 1/X
362  43 RCL
363  05  05
364  55  ÷
365  02  2
366  55  ÷
367  43 RCL
368  04  04
369  95  =
370  42 STO
371  06  06
372  58 FIX
373  01  01
374  87 IFF
375  02  02
376  53  (
377  43 RCL
378  04  04
379  91 R/S
380  43 RCL
381  05  05
382  91 R/S
383  43 RCL
384  06  06
385  91 R/S
386  76 LBL
387  53  (
388  43 RCL
389  02  02
390  91 R/S
391  43 RCL
392  05  05
393  91 R/S
394  43 RCL
395  06  06
396  91 R/S
397  76 LBL
398  33 X²
399  43 RCL
400  00  00
401  55  ÷
402  53  (
403  01  1
404  75  -
405  53  (
406  53  (
407  03  3
408  94 +/-
409  65  ×
410  53  (
411  53  (
412  43 RCL
413  13  13
414  34 √X
415  55  ÷
416  43 RCL
417  18  18
418  75  -
419  43 RCL
420  15  15
421  54  )
422  55  ÷
423  43 RCL
424  16  16
425  54  )

426  22 INV
427  45 Yˣ
428  43 RCL
429  17  17
430  54  )
431  22 INV
432  23 LNX
433  54  )
434  54  )
435  95  =
436  42 STO
437  04  04
438  61 GTO
439  23 LNX
440  76 LBL
441  22 INV
442  43 RCL
443  00  00
444  55  ÷
445  43 RCL
446  04  04
447  95  =
448  42 STO
449  14  14
450  87 IFF
451  01  01
452  42 STO
453  32 X:T
454  93  .
455  09  9
456  05  5
457  22 INV
458  77  GE
459  43 RCL
460  53  (
461  53  (
462  43 RCL
463  14  14
464  45 Yˣ
465  43 RCL
466  09  09
467  65  ×
468  43 RCL
469  08  08
470  85  +
471  43 RCL
472  07  07
473  54  )
474  65  ×
475  43 RCL
476  18  18
477  54  )
478  33 X²
479  42 STO
480  13  13
481  55  ÷
482  01  1
483  00  0
484  95  =
485  42 STO
486  02  02
487  61 GTO
488  23 LNX
489  76 LBL
490  43 RCL
491  53  (
492  53  (
493  53  (
494  53  (
495  01  1
496  75  -
497  43 RCL
498  14  14
499  54  )
500  23 LNX
501  55  ÷
502  03  3
503  94 +/-
504  54  )
505  45 Yˣ
506  43 RCL
507  17  17
508  65  ×
509  43 RCL
510  16  16
511  85  +
```

```
512  43 RCL
513  15  15
514  54  )
515  65  ×
516  43 RCL
517  18  18
518  54  )
519  33  X²
520  42 STO
521  13  13
522  55  ÷
523  01  1
524  00  0
525  95  =
526  42 STO
527  02  02
528  61 GTO
529  23 LNX
530  76 LBL
531  42 STO
532  43 RCL
533  03  03
534  23 LNX
535  45  YX
536  01  1
537  93  .
538  00  0
539  01  1
540  65  ×
541  93  .
542  09  9
543  02  2
544  05  5
545  85  +
546  93  .
547  08  8
548  02  2
549  05  5
550  95  =
551  42 STO
552  07  07
553  43 RCL
554  03  03
555  45  YX
556  93  .
557  01  1
558  02  2
559  03  3
560  04  4
561  65  ×
562  05  5
563  93  .
564  09  9
565  06  6
566  94 +/-
567  85  +
568  05  5
569  93  .
570  01  1
571  95  =
572  42 STO
573  08  08
574  43 RCL
575  03  03
576  23 LNX
577  45  YX
578  93  .
579  00  0
580  09  9
581  02  2
582  05  5
583  65  ×
584  01  1
585  93  .
586  09  9
587  07  7
588  02  2
589  75  -
590  93  .
591  08  8
592  01  1
593  03  3
594  95  =
595  42 STO
596  09  09
597  53  (
598  43 RCL
599  03  03
600  65  ×
601  01  1
602  93  .
603  05  5
604  94 +/-
605  54  )
606  22 INV
607  23 LNX
608  65  ×
609  03  3
610  93  .
611  04  4
612  85  +
613  01  1
614  93  .
615  01  1
616  01  1
617  02  2
618  95  =
619  42 STO
620  15  15
621  53  (
622  53  (
623  43 RCL
624  03  03
625  65  ×
626  02  2
627  93  .
628  03  3
629  05  5
630  94 +/-
631  54  )
632  22 INV
633  23 LNX
634  65  ×
635  02  2
636  93  .
637  04  4
638  06  6
639  94 +/-
640  85  +
641  93  .
642  09  9
643  05  5
644  08  8
645  54  )
646  33  X²
647  42 STO
648  16  16
649  87 IFF
650  02  02
651  54  )
652  53  (
653  53  (
654  53  (
655  43 RCL
656  18  18
657  55  ÷
658  43 RCL
659  13  13
660  34  √X
661  75  -
662  43 RCL
663  07  07
664  54  )
665  55  ÷
666  43 RCL
667  08  08
668  54  )
669  22 INV
670  45  YX
671  43 RCL
672  09  09
673  54  )
674  42 STO
675  14  14
676  35 1/X
677  65  ×
678  43 RCL
679  00  00
680  95  =
681  42 STO
682  04  04
683  76 LBL
684  45  YX
685  53  (
686  43 RCL
687  15  15
688  55  ÷
689  53  (
690  01  1
691  75  -
692  43 RCL
693  14  14
694  54  )
695  54  )
696  45  YX
697  43 RCL
698  16  16
699  65  ×
700  02  2
701  65  ×
702  43 RCL
703  18  18
704  95  =
705  42 STO
706  05  05
707  61 GTO
708  15  E
709  76 LBL
710  54  )
711  53  (
712  43 RCL
713  18  18
714  55  ÷
715  53  (
716  43 RCL
717  14  14
718  [illegible]
719  [illegible]
720  [illegible]
721  [illegible]
722  43 RCL
723  [illegible] 06
724  85  +
725  43 RCL
726  07  07
727  [illegible]
728  [illegible]
729  [illegible]
730  42 STO
731  [illegible]
732  75  -
733  01  1
734  00  0
735  95  =
736  42 STO
737  02  02
738  61 GTO
739  [illegible]
740  76 LBL
741  52  EE
742  00  0
743  35 1/X
744  91 R/S
745  76 LBL
746  44 SUM
747  01  1
748  94 +/-
749  34  √X
750  91 R/S
```

CIRCULAR
FIRE SHAPE

```
000  76 LBL
001  16  A'
002  22 INV
003  58 FIX
004  22 INV
005  86 STF
006  01  01
007  47 CMS
008  91 R/S
009  42 STO
010  00  00
011  91 R/S
012  42 STO
013  01  01
014  32 X:T
015  43 RCL
016  01  01
017  91 R/S
018  42 STO
019  02  02
020  22 INV
021  77  GE
022  52  EE
023  67  EQ
024  52  EE
025  61 GTO
026  24  CE
027  76 LBL
028  17  B'
029  22 INV
030  58 FIX
031  86 STF
032  01  01
033  47 CMS
034  91 R/S
035  42 STO
036  00  00
037  32 X:T
038  43 RCL
039  00  00
040  91 R/S
041  42 STO
042  01  01
043  91 R/S
044  42 STO
045  04  04
046  22 INV
047  77  GE
048  52  EE
049  67  EQ
050  52  EE
051  76 LBL
052  24  CE
053  43 RCL
054  01  01
055  65  ×
056  01  1
057  00  0
058  95  =
059  42 STO
060  13  13
061  43 RCL
062  02  02
063  65  ×
064  01  1
065  00  0
066  95  =
067  42 STO
068  13  13
069  53  (
070  43 RCL
071  12  12
072  55  ÷
073  89  π
074  54  )
075  34  √X
076  95  =
077  42 STO
078  18  18
079  87 IFF
080  01  01
081  34  √X
082  53  (
083  43 RCL
084  13  13
085  55  ÷
086  43 RCL
087  12  12
088  54  )
089  23 LNX
090  65  ×
091  02  2
092  95  =
093  42 STO
094  19  19
095  06  6
096  42 STO
097  06  06
098  76 LBL
099  22 INV
100  53  (
101  43 RCL
102  19  19
103  22 INV
104  23 LNX
105  65  ×
106  53  (
107  43 RCL
108  19  19
109  75  -
110  01  1
111  54  )
112  85  +
113  01  1
114  54  )
115  55  ÷
116  53  (
117  43 RCL
118  19  19
119  22 INV
120  23 LNX
121  75  -
122  53  (
123  43 RCL
124  13  13
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268  23 LNX
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271  00  0
272  35 1/X
273  91 R/S
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ERRATA

USDA Forest Service Research Note INT-268, January 1980
Frank A. Albini and Carolyn H. Chase
Fire Containment Equations for Pocket Calculators

Page 7, Case C

Case C. Circular Fire Shape $(1 \le L/W < 1.2)$

$$A_B/A_o = \left(\exp(Z) - 1\right)/Z$$

$$P/2r(C) = \left(\exp(Z/2) - 1\right)(V_L/V_F)$$

$$Z = 2\pi/\ (V_L/V_F)^2 - 1\ ^{1/2}$$

Page 7, Case A (line 9)

$$A_{22} = 0.55/(L/W-1) - 2/(L/W)^3$$

MONTANA
IDAHO
ADA
UTAH

Research Note

USDA FOREST SERVICE INT-269
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507-25th STREET, OGDEN, UTAH 84401

December 1979

PROGRESS TOWARD LOCATING LIGHTNING FIRES

Don J. Latham[1]

ABSTRACT

Systems to enable land managers to locate, evaluate, and counter the fire threat of lightning storms are in the early stages of development. In the western U.S. and Alaska, the Bureau of Land Management has established networks of instruments that locate lightning strikes by means of recorded azimuths. Further research could add important capabilities: identifying and counting strikes with fire-starting potential, estimating ignition probabilities under various fuel and weather conditions, and predicting fire behavior immediately after ignition.

KEYWORDS: Lightning, lightning location, fire location,
wildland fires, fire planning

Statistics from the Division of Cooperative Fire Control show that each year, in the Western States, lightning starts about 44 percent of the approximately 20,000 fires that occur. Lightning also accounts for about 60 percent of the million or so acres burned on private, State, and Federal lands. For Regions 1 and 3 of the USDA Forest Service, these percentages are significantly higher. Although lightning fires are relatively rare and unimportant in the eastern half of the Nation, southeastern forests have been shown to be more susceptible to insect attacks as a result of lightning damage to trees (Taylor 1977).

New trends in fire management require fresh approaches to fire suppression. Contrary to what one might expect, allowing some fires to burn for ecological reasons calls for more, not less, fire management activities than employed in the past. At the same time, the costs are climbing and funds are limited. For these reasons, fire managers need new technology that will reduce costs.

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[1] Research meteorologist/physicist located at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana.

A new lightning locating device offers considerable promise for improving management and reducing costs. The device locates cloud-to-ground lightning strokes (Noggle and others 1976). A six-station network now covers Alaska. Another is being set up to cover the Great Basin region. Both of these lightning direction-finding networks are sponsored by the U.S. Department of Interior, Bureau of Land Management.

The Great Basin network consists of 12 stations, each having a device that measures the azimuth to lightning. The azimuths are combined at several central stations to compute lightning storm locations, which will then be sent to fire control organizations. Unfortunately, this network will have severe limitations because presently we have no means to assess the output in terms of fire behavior or to use the output in pre-suppression and suppression operations. The purpose of this paper is to describe efforts toward developing a system that will assist fire managers not only to locate lightning storms but also to predict how many fires are likely to start and how fast they will burn.

For many years, fire suppression organizations have relied on intelligent adaptive computers--lookouts--to locate lightning and detect fires. Lookouts can observe lightning discharges and storm locations, and subsequently monitor strike locations for the appearance of fire. Lookouts can also keep track of many of the variables influencing the fire growth process, and make decisions based on this input. Since their inception, lookouts have detected nearly half of all lightning fires in Region 1 (Barrows 1951, 1977[2]).

The effectiveness of the lookout is demonstrated in figure 1. Here we show lightning-fire detection times for four forests in Region 1, comparing lookouts, pilots, and others, including road patrols and airborne infrared scanners. This figure illustrates that, within 5 hours, lookouts catch almost three-fourths of all fires that grow into class B or larger. On the other hand, pilots take almost 20 hours to accomplish the same task.

Detection times differ because lookouts know where to look for potential lightning-fires. Decreasing aircraft detection time to that of lookouts could reduce burned acreage and effect more efficient use of aircraft and firefighters. However, past attempts to substantiate this possibility have been unsuccessful.

In the absence of a locating and timing system, detection time cannot be accurately established. With few exceptions, detection times appearing on Forest Service Form 5100-29 are, at best, educated guesses by airborne observers and others. Therefore, it is impossible to use their data (fig. 1) as baselines from which to measure the effectiveness of a location system. A location system is thus necessary to establish the usefulness of a location system. We can, however, speculate that a decrease in detection time would reduce fire size.

We were able to examine the probabilities of fire growth in available statistics (data from Region 1, western forests, 1946-1973). The following gives the escape probability by fire class:

Fire size	A	B	C	D
Probability of fire becoming larger	0.15	0.11	0.25	0.58

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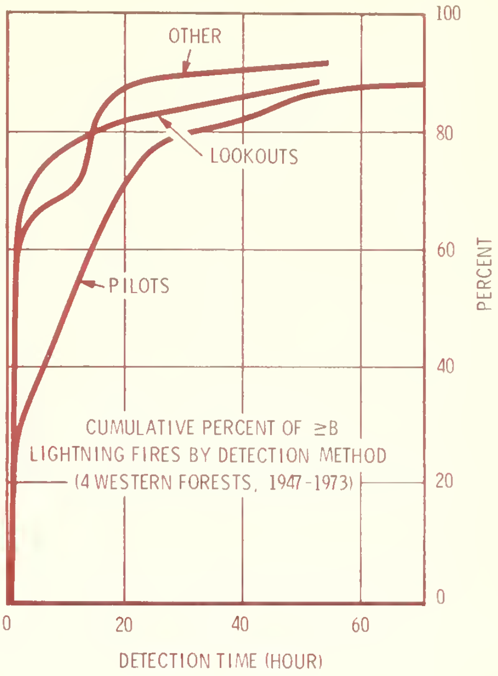
[2] Lightning fires in Northern Rocky Mountain Forests. Final Rep., Contract 16-440-CA. Intermt. For. and Range Exp. Stn., Missoula, Mont.

Figure 1.--Cumulative probability for detection time as reported on Forest Service form 5100-29 for four forests in Region 1.



Simply put, the probabilities are as follows: If a fire is presently class C, for example, the odds are 1 in 4 that it will grow to be a class D or larger fire; 25 percent of class C fires get away. From these probabilities, we see that about 2 percent of all lightning fires become larger than class B. If these odds could be reduced, a definite cost savings would result, and there is a good chance that a properly developed lightning locating system would accomplish this. Earlier detection, resulting from knowing where to look, should speed overall response time. This in turn would decrease the chance of escape to the potentially disastrous class C size.

Forest Service fire management personnel have recently called for a thorough overhaul of fire planning and are presently developing a new fire planning guide to replace the 1972 version. In the existing version, the basis for scheduling air patrols is vague and the times of day for such patrols are fixed. A lightning locating system, properly applied, would enable these patrols to be made as needed. In addition, those storms that presently "sneak by" a sparse lookout network, as in wilderness areas, could be caught. A few years of data would provide a much better estimate of the number of airplane hours required. A fire plan incorporating a lightning locating system might also include, when fire danger is extreme, the use of aircraft with smokejumpers on board, or retardant-carrying aircraft vectored to the lightning locations without an actual fire having been reported.

Fires detected more than 1 day after ignition have traditionally been called "holdover" fires. Because part of a lightning locating system is data storage, a memory of past lightning strikes would help shorten detection time because observers will know where to look.

So far we have discussed only the suppression uses of a lightning locating system. What about other possibilities? Obviously, such a system would provide good data on detection times for evaluating responses of all types of detection methods. The raw data would also be beneficial for other research studies, such as establishing a lightning climatology, and also for updating the system itself. Applications in other areas of fire management are also possible.

Long range fire planning will benefit through use of combined location and fire data. Thunderstorm "alleys" can be identified and the probability of naturally-occurring fire can be better assessed, resulting in improved fuel treatment prescriptions. In addition, fire probability maps can be generated and used in forest models, aiding in long-range planning. These maps can also be used as inputs to FOCUS-like models for teaching and evaluating response to fire occurrence. All of this can be done because the lightning-fire locating system will respond to historical and simulated lightning scenarios, as well as real-time occurrences.

Having laid down some possible uses for a system to locate lightning fires, we should review design criteria and the research necessary. For operations and planning, we are interested in fires, not lightning. Therefore, a primary consideration is the relationship between lightning and fires. Figure 2 illustrates the chain of events leading to a "successful" or "reported" lightning fire. That portion of the figure within the dotted lines is hidden from observation because of the random nature of its occurrence. That is, if an observer happened to be on the spot, the phenomena could be seen quite clearly, but the chance of one being there is vanishingly small.

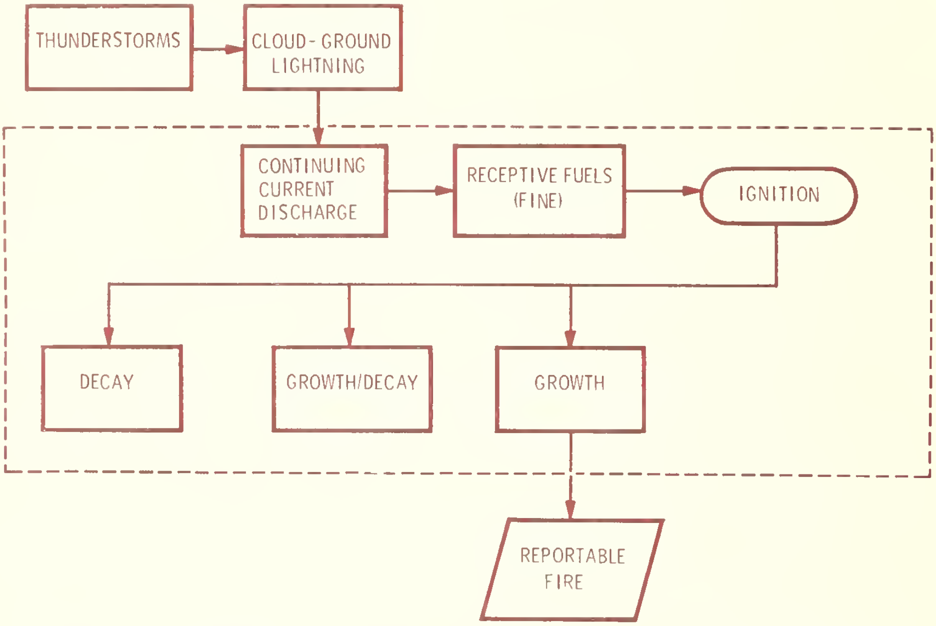


Figure 2.--Events involved in the generation of a lightning-fire. Those within dotted lines would be visible to an observer on the spot.

A lightning fire detection system includes a model for those hidden processes that lead to a reportable fire. There are two basic approaches to this model. One is to gather data on the variables involved and to produce a purely empirical model (Nickey 1976; Kourtz 1974). The other approach is to construct a purely physical model from first principles. Neither of these approaches is very efficient because of the large variances involved and the effect of random factors. A better approach is to combine the two into a semi-empirical form which allows for easy modification as data is obtained.

Some of the links for modeling the lightning fire chain of figure 1 have been forged, including characterizing lightning and the relationship between types of lightning strokes and ignition of fires. Fuquay (1972) demonstrated that by far the largest part of lightning fires can be linked to certain cloud-to-ground lightning strokes--those containing a continuing current. Most cloud-to-ground discharges can be considered similar to the spark generated by shuffling along a rug or the ignition spark in an automobile engine. The continuing current, on the other hand, is more like the arc from an arc welder. In the northern Rocky Mountains, approximately 20 percent of cloud-to-ground strokes are accompanied by arc-type discharges. Hence roughly 20 percent of the cloud-to-ground strokes are potential fire starters. Further, the probability that a cloud-to-ground flash will ignite forest fuels increases with the duration of the continuing current because total energy released is higher.

The system for locating lightning must differentiate between these likely fire starters and ordinary cloud-to-ground discharges. Furthermore, any model, whether based on physics or statistics, should use the energy released by the continuing current as a means of estimating fire ignition potential.

The next link to consider is the relationship between the continuing current and the on-the-ground conditions that determine *ignition* probability. The link is partially completed. A model for lightning fire ignition (Fuquay and others 1979) was developed for the National Fire-Danger Rating System (NFDRS). The model is a hybrid because it combines the physics of ignition with statistical variables dealing with continuing current energies and thunderstorm behavior. Although not specifically designed for real-time use, the model is readily adaptable for it.

The final link in the lightning fire chain is the growth of an ignition to a reportable fire. It is the modeling of this link that is the most intransigent and needs the most work at this time. A combination of laboratory and field investigations will be necessary to obtain data for developing a fire probability model.

What other criteria can we set for the system? We have to immediately provide information from the locating device and probability model to the land managers and store the data in an easily accessed fashion for future use. We must try to implement the system at the lowest cost and with the greatest flexibility. Therefore, extensive use of large computer facilities should be avoided. Short-term local storage will be necessary for locating holdover fires and possible insect-infested areas and for determining seasonal trends. Long-term local storage may also be dictated by fire planning needs. The form of display and storage is left as a task to be done.

The development of a lightning-fire locating system as outlined above started with the establishment of the lightning locating devices by the Bureau of Land Management. The remainder of the system is, as we discussed earlier, in various stages of construction.

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Research Note

USDA FOREST SERVICE INT-270
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507-25th STREET, OGDEN, UTAH 84401

September 1979

RESPONSE OF GRAND FIR, WESTERN HEMLOCK, WESTERN WHITE PINE, WESTERN LARCH, AND DOUGLAS-FIR TO NITROGEN FERTILIZER IN NORTHERN IDAHO

by

Russell T. Graham and Jonalea R. Tonn[1]

ABSTRACT

*Two study areas were used to assess the response of mixed, young, coniferous forests to nitrogen (N) fertilizer in the form of urea. Significant (P<0.05) responses in diameter growth to fertilization were noted at one of the study areas. Significant differences were detected between the height growth means in both study areas. Differences between the height and diameter growth means for the 200 lb N per acre (224 kg N per ha) treatment and the 400 lb N per acre (448 kg N per ha) treatment were not significant. When each species was analyzed separately only grand fir (*Abies grandis *[Dougl.] Lindl.) and Douglas-fir (*Pseudotsuga menziesii var. glauca *[Beissn.] Franco) had a significant response to fertilizer application.*

KEYWORDS: Fertilization, western white pine, grand fir, diameter growth, height growth.

Past studies indicate that fertilization may have potential as a silvicultural tool in young forests in northern Idaho. Loewenstein and Pitkin (1963) reported height growth increases (compared with elongation prior to fertilization) as high as 286 percent for grand fir (*Abies grandis* [Dougl.] Lindl.) and 187 percent for western white pine (*Pinus monticola* Dougl.). Ryker and Pfister (1967) also showed a significant growth response to fertilizer in western white pine in thinned stands. More information is needed on the amount and duration of response that can be expected from various levels of fertilizer applications. Additional information concerning which species have the greatest potential to respond to fertilization is also important. The objective of this trial was to study the effects of urea fertilization on growth characteristics in a young stand of mixed conifers. This paper reports on diameter and height growth responses of five conifers.

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[1] Research forester and forestry technician, respectively, located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

STUDY AREAS

Fertilization trials were established at both the Deception Creek Experimental Forest (DCEF) and the Priest River Experimental Forest (PREF). Both studies were in young natural stands of mixed conifers in the *Tsuga heterophylla/Pachistima myrsinites* habitat type (Daubenmire and Daubenmire 1968).

The DCEF study occupies 4.5 acres (1.8 ha) on a north-facing slope in lower Snyder Creek. The lower half is on gentle slopes; however, the upper half has slopes up to 50 percent. The stand was seed-tree cut in 1952, and the seed trees were removed in 1965.

In 1971, the stand was cleaned to a spacing of approximately 10 feet (3.05 m) by 10 feet (3.05 m). An effort was made to leave a mixture of species including:

western white pine (*Pinus monticola* Dougl.)
western larch (*Larix occidentalis* Nutt.)
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco)
grand fir (*Abies grandis* [Dougl.] Lindl.)
western hemlock (*Tsuga heterophylla* [Raf.] Sarg.)
Engelmann spruce (*Picea engelmannii* Parry)
subalpine fir (*Abies lasiocarpa* [Hook.] Nutt. var. *lasiocarpa*)

The DCEF study area was fertilized in the fall of 1972. At the time of fertilization the stand had a mean diameter of 1.48 inches (3.76 cm) and a mean height of 10.64 feet (3.24 m). The cleaning resulted in a stand containing 370 trees per acre (913.6 trees per ha).

The PREF study area consists of 3 acres (1.2 ha) in the lower part of the Benton Creek Drainage. The stand originated in 1955 after removal and dozer-clearing of the previous stand. The slope percent ranges from 25 to 35. In the fall of 1971, the stand was cleaned to an average spacing of 12 feet (3.66 m) by 12 feet (3.66 m). A mixture of species were left including:

western white pine (*Pinus monticola* Dougl.)
western larch (*Larix occidentalis* Nutt.)
Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco)
grand fir (*Abies grandis* [Dougl.] Lindl.)
lodgepole pine (*Pinus contorta* Dougl.)
western hemlock (*Tsuga heterophylla* [Raf.] Sarg.)
western redcedar (*Thuja plicata* Donn)
Engelmann spruce (*Picea engelmannii* Parry)
ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*)

The PREF study area was fertilized in the early spring of 1973. The stand had 283 trees per acre (698.8 trees per ha) at the time of fertilization. The mean stand diameter was 3.32 inches (8.43 cm) and the mean height of the stand was 21.56 feet (6.57 m).

METHODS

The DCEF trial was divided into five blocks with three plots each. Three treatments were randomly assigned: no fertilization (treatment 1); urea applied at the rate of 200 pounds of N per acre (224 kg N per ha) (treatment 2); and urea applied at the rate of 400 pounds of N per acre (448 kg N per ha) (treatment 3). A subplot of 0.04 acres (0.016 ha) was established and trees within the subplot were tagged and measured.

A similar design was used at the PREF but with only two treatments. Six plots, each approximately 0.5 acre (0.2 ha) were established and divided into three 2-plot blocks. The treatments, either no fertilizer (treatment 1) or urea applied at the rate of 200 pounds of N per acre (224 kg N per ha) (treatment 2), were assigned at random to the plots in each of the blocks. Similar subplots of 0.1 acres (0.04 ha) were established and trees within them tagged and measured.

Diameter at breast height and total height of the tagged trees were taken in 1973, 1974, and 1977. Periodic mean annual diameter growths and periodic mean annual height growths for the 1973-1977 period were computed for trees alive during 1977.

For each study area, fertilizer treatments were compared and 1973 heights and diameters were used as covariates. Duncan's multiple range test was used to detect which treatment means were significantly different at the 5 percent level. To test the significance of species, a covariate analysis (with species as one of the main effects) was performed. All means used in the comparisons were adjusted for the differences in heights and diameters that existed at the beginning of the study.

RESULTS

Diameter Growth

Periodic mean annual diameter growth at DCEF had a significant ($P<0.05$) 24 percent response to fertilization. Both fertilized treatments had periodic mean annual diameter growth means of 0.36 inch (0.914 cm) (fig. 1). The unfertilized treatment had a diameter growth mean of 0.29 inch (0.737 cm).

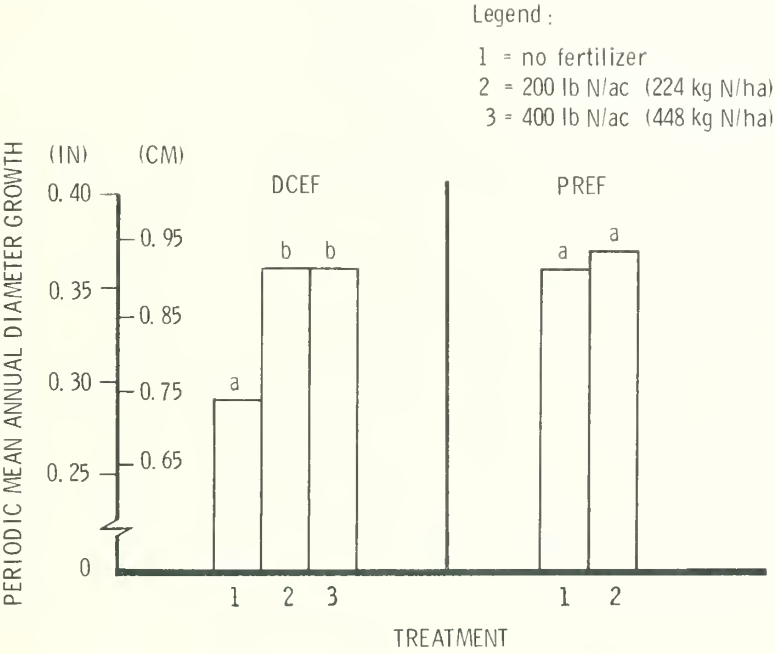

Figure 1.--Periodic mean annual diameter growth by treatment at DCEF and PREF, all species. Different letters indicate significant differences ($P< 0.05$).

No significant response to fertilization was detected in periodic mean annual diameter growth at PREF (fig. 1). The diameter growth mean for the unfertilized plot was 0.36 inch (0.914 cm) and, for the fertilized plots, it was 0.37 inch (0.940 cm).

Height Growth

Deception Creek Experimental Forest periodic mean annual height growth had a 10 percent response to the light application of fertilizer and an 18 percent response to the heavy application. The periodic mean annual height growth for the unfertilized treatment was 1.14 feet (0.347 m) (fig. 2). For the fertilized treatments, 2 and 3, the height growth means were 1.25 feet (0.381 m) and 1.35 feet (0.411 m), respectively. The unfertilized treatment height growth mean was significantly smaller than the two fertilized treatments. The difference between the height growth means for the two levels of fertilization was not significant.

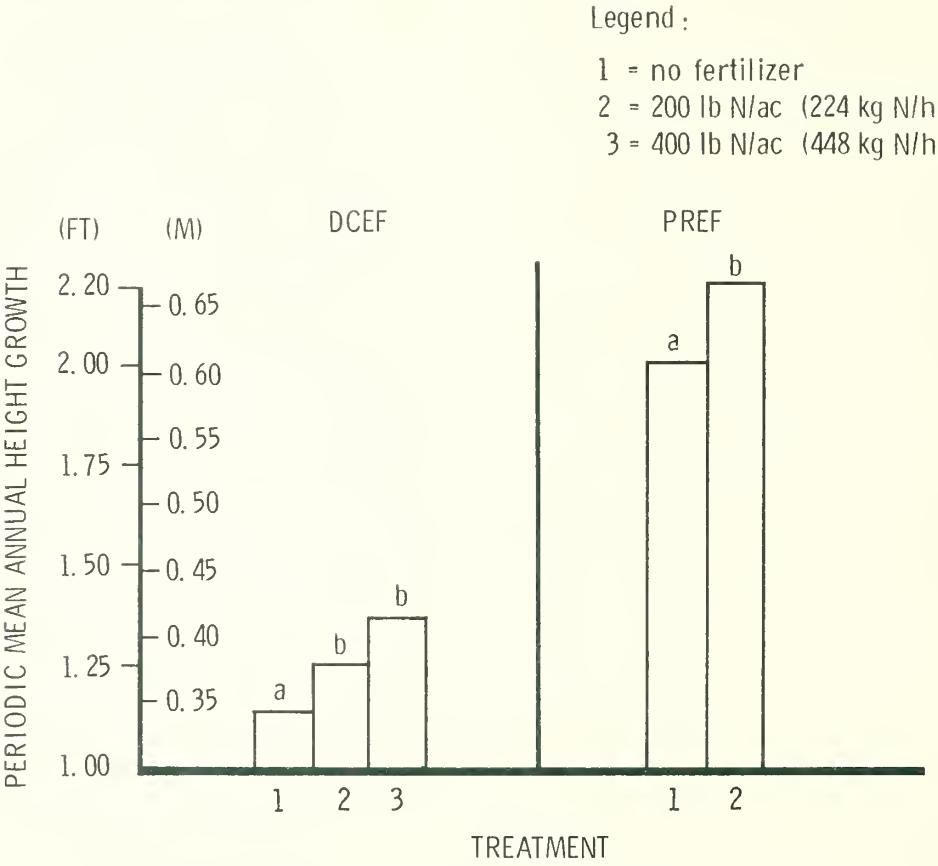

Figure 2.--Periodic mean annual height growth by treatment at DCEF and PREF, all species. Different letters indicate significant differences ($P<0.05$).

At PREF a 9-percent increase in height growth was measured for the fertilized treatment. The unfertilized treatment had a height growth mean of 2.00 feet (0.610 m) and the fertilized treatmennt, 2.18 feet (0.664 m) (fig. 2). The height growth means were significantly different.

Species Differences

The covariate analysis that included species as one of the main effects indicated that species was significant in explaining part of the variation in both diameter and height growth. Therefore, a separate covariate analysis was performed for those species having greater than 10 trees in each of the treatments. At the DCEF, grand fir and western hemlock were the only species having an adequate number of observations for analysis. At the PREF, white pine, western larch and Douglas-fir had sufficient records for analysis.

The DCEF grand fir periodic mean annual diameter growth showed a 30 percent response for the light application of fertilizer and a 26 percent response for the heavy application. The unfertilized treatment mean for diameter growth was 0.27 inch (0.68 cm) compared to 0.35 inch (0.89 cm) and 0.34 inch (0.86 cm) for the fertilized treatments 2 and 3, respectively (fig. 3). The differences in the diameter growth means for the two levels of fertilization were nonsignificant.

Grand fir height growth also had a significant response to fertilization. There was a 24 percent response with the light application of fertilizer and a 45 percent response with the heavy application. The difference between means of the two levels of fertilizer was nonsignificant. The periodic mean annual height growth for the unfertilized treatment was 1.10 feet (0.34 m) (fig. 4). The height growth means for the fertilized treatments 2 and 3 were 1.36 feet (0.41 m) and 1.59 feet (0.48 m), respectively.

No significant differences in either diameter growth or height growth were detected among the three treatment means for western hemlock (fig. 3, 4).

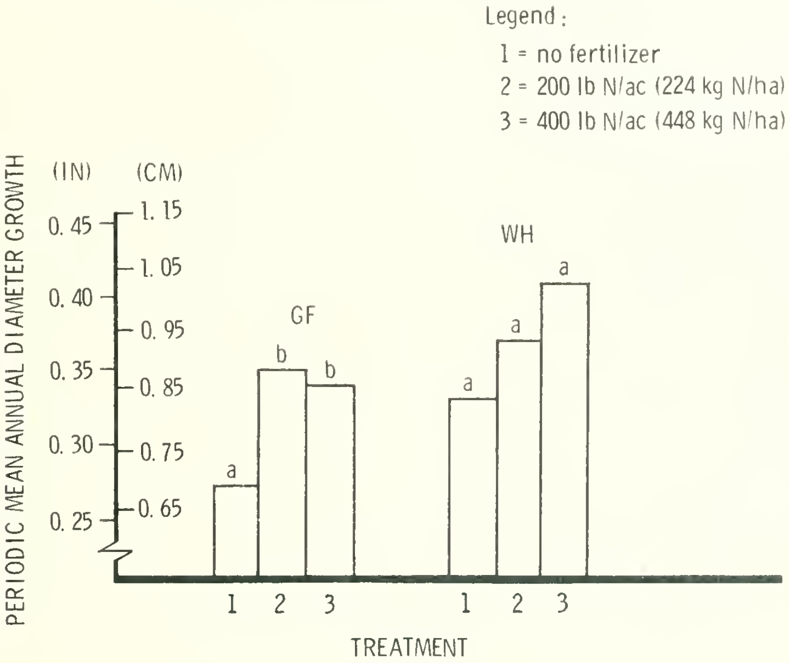

Figure 3.--Periodic mean annual diameter growth by treatment at DCEF. Different letters indicate significant differences ($P<0.05$).

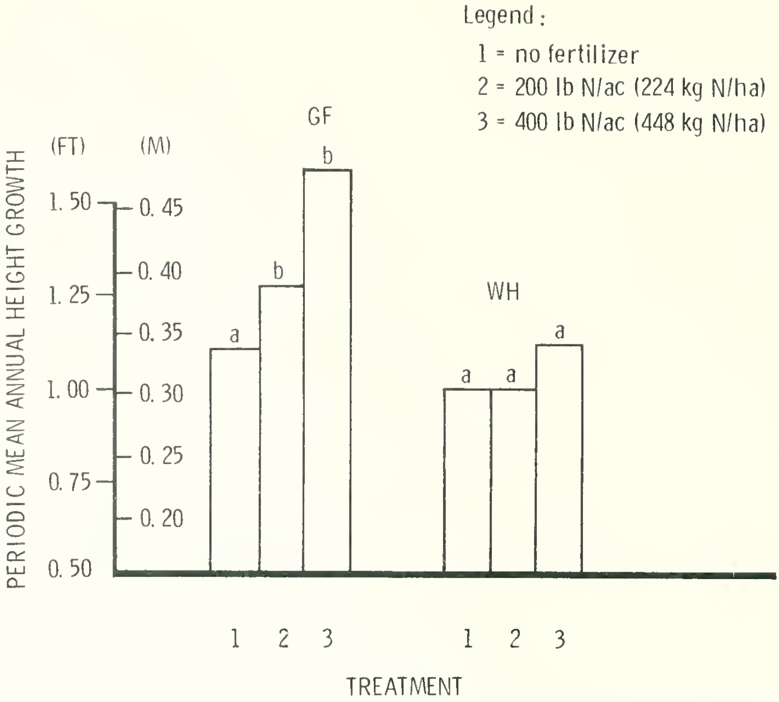

Figure 4.--Periodic mean annual height growth by treatment at DCEF. Different letters indicate significant differences (P<0.05).

At the PREF, no significant differences between the unfertilized treatment means and fertilized treatment means for either height growth or diameter growth were detected for white pine or western larch (fig. 5, 6). Douglas-fir had a significant response to fertilization in height growth but not in diameter growth. The Douglas-fir height growth treatment mean for the unfertilized treatment was 1.84 feet (0.56 m) compared to the fertilized treatment of 2.15 feet (0.66 m) (fig. 6).

DISCUSSION

The increase in tree growth due to fertilization can be quite variable. Species composition may influence results, such as the different responses noted at PREF and DCEF. Also the timing of fertilization (spring versus fall) may have contributed to the different responses of the two study areas.

How an individual species responds to the application of fertilizer can also be variable. In our study, the response of grand fir was similar to the findings of Loewenstein and Pitkin (1963). In contrast, our study showed less response to fertilization in white pine than did the findings of Ryker and Pfister (1967).

The significant responses found 5 years following fertilization may not hold in the future or, conversely, more significant differences in tree growth may appear in the future. This study will continue for at least 5 more years. During this time additional stand and site descriptors will be sought to help explain the different responses to fertilization on the two areas.

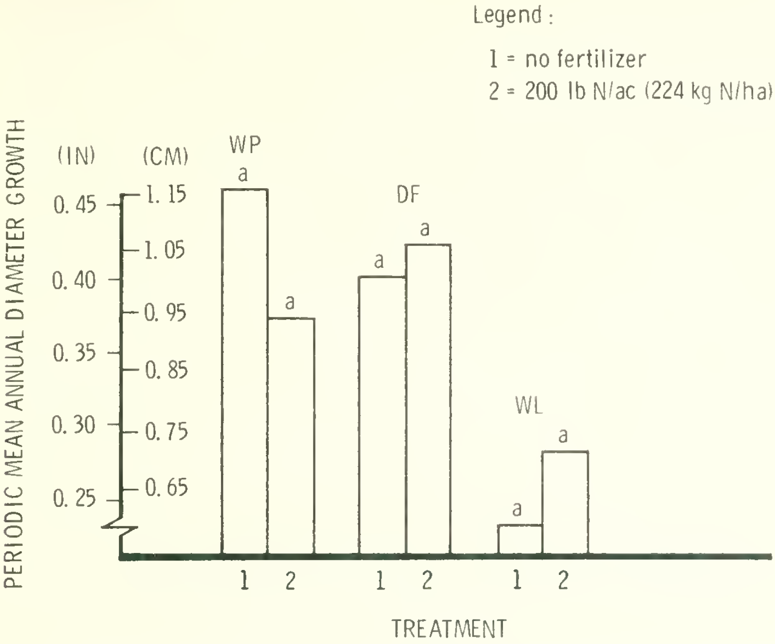

Figure 5.--Periodic mean annual diameter growth by treatment at PREF. Different letters indicate significant differences (P<0.05).

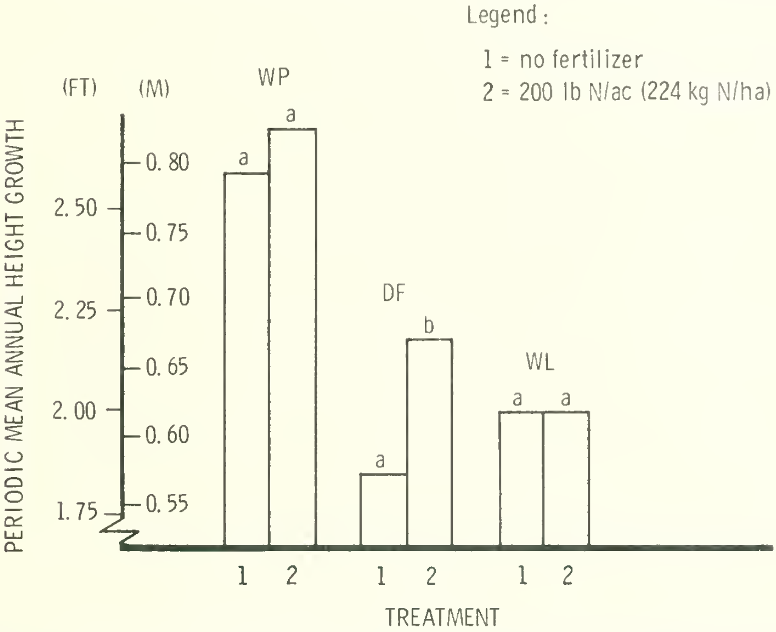

Figure 6.--Periodic mean annual height growth by treatment at PREF. Different letters indicate significant differences (P<0.05).

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Research Note INT-271

August 1979

ELK-ASPEN RELATIONSHIPS ON A PRESCRIBED BURN[1]

Joseph V. Basile[2]

ABSTRACT

Elk use of aspen clones was deterred only one winter following prescribed fire. Numbers of aspen suckers on the nine burned clones increased 178 percent in 3 years, but the response varied greatly among clones. Elk browsing the third winter after burning averaged 44 percent of current annual growth, and eliminated incremental height growth from the previous summer. It is not yet known whether prescribed burning can rejuvenate decadent aspen stands under existing elk browsing pressures.

KEYWORDS: elk, aspen, fire

The decline in aspen (*Populus tremuloides* Michx.) and the paucity of successful regeneration has concerned resource managers in the Jackson Hole area of northwestern Wyoming for several decades. This decline generally has been attributed to overbrowsing by elk (Murie 1944; Beetle 1962). Gruell (in press), however, raised the question of whether fire suppression might be equally responsible for the aspen decline. He has described the historic role of wildfire in creating and maintaining vigorous aspen stands, and he has expressed the belief that prescribed fire can rejuvenate decadent stands despite existing levels of ungulate use.

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[1] This paper was presented at the Elk Ecology and Management Symposium, April 3-5, 1978, Univ. of Wyo., Laramie.

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Bartos and Mueggler (in press) described an experimental burn of aspen clones on the Gros Ventre winter range, and reported initial effects of the fire on forage production. I will report on the effects of that burn on elk use of the area, on aspen suckering, and on elk use of those suckers.

Methods

Counts of aspen suckers in each of the 10 clones were from five 4-m^2 (43-ft^2) microplots nested within each of four 100-m^2 (1,076-ft^2) macroplots. Since 1974, I have assessed elk use by pellet group counts on eight 0.004 hectare (0.01 acre) plots per clone each spring.

Elk Use

Gruell (personal communication) reported pellet group counts on the study area in 1972 and 1973 as 622 and 787 per hectare (252 and 318 per acre), respectively. My sampling in 1974 showed 1,041 pellet groups per hectare (421 per acre), which together with Gruell's findings indicated an average preburn density of approximately 812 groups per hectare (329 per acre).

Burning in the late summer of 1974 rendered the area relatively unattractive to elk in the ensuing few months, as is evidenced by the 279 pellet groups per hectare (113 per acre) counted in the spring of 1975. But elk use returned to preburn levels in the second and third postburn winters, when pellet groups numbered 978 and 724 per hectare (396 and 293 per acre), respectively. This pattern of elk use--that is, the first-year decline from, but rapid return to preburn levels--was fairly consistent among the 10 aspen clones (fig. 1 and 2).

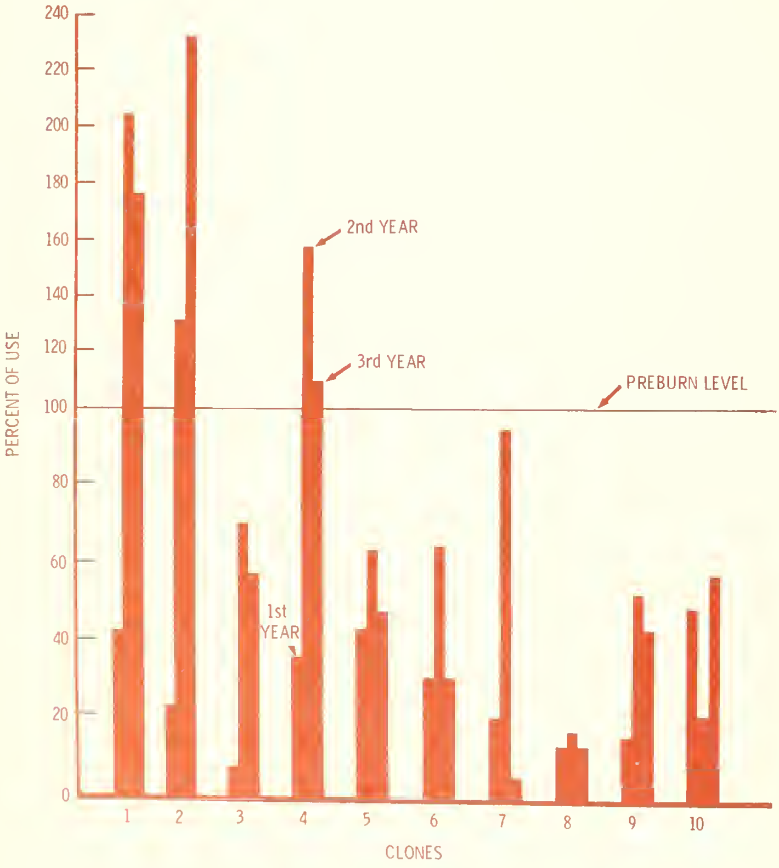

Figure 1.--Pattern of elk use on 10 aspen clones in three consecutive years after burning, expressed as a percentage of use in the year before the fire.

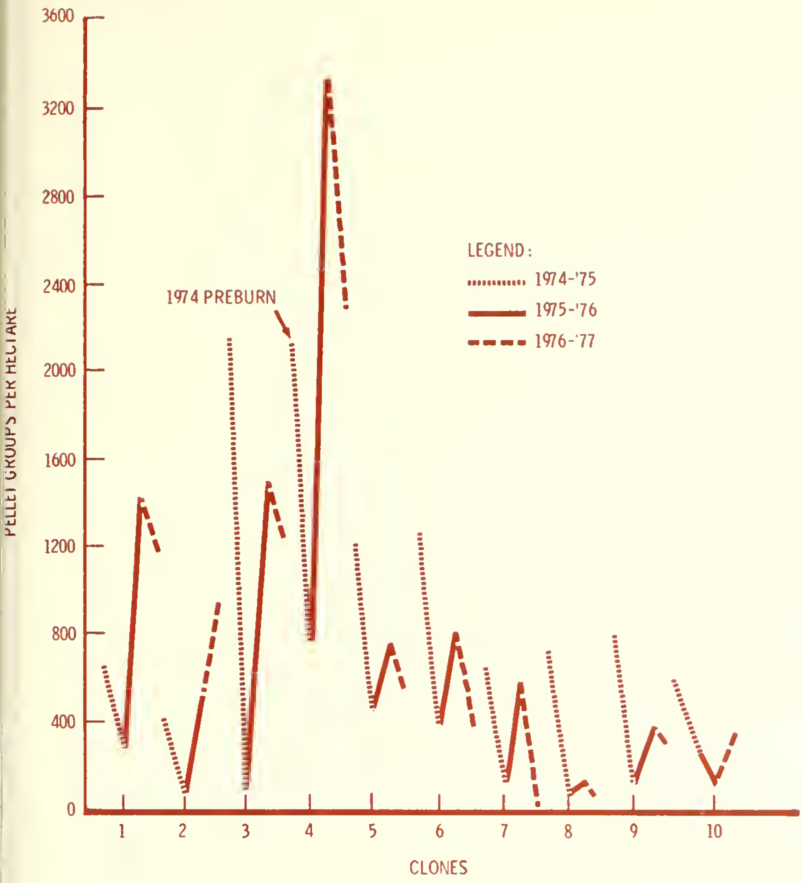

Figure 2.--Pellet group counts on 10 aspen clones in one preburn and three postburn years.

Sprout Production

How did the fire affect aspen suckering? The year after the fire, the nine burned clones averaged an 87 percent increase in suckering, but the response was by no means uniform (fig. 3). Suckering decreased 62 percent on one clone (No. 4), remained unchanged on three clones (Nos. 3, 6, and 9), and increased on a fifth clone (No. 1) by only half the percentage rate that suckering on the control clone (No. 10) did. Thus, suckering on only four burned clones (Nos. 2, 5, 7, and 8) increased proportionately over that of the control in the first year; however, a somewhat more uniform response was noted in the second and third years. These same four clones continued to outperform the control. In addition, two of the other clones (Nos. 3 and 6) showed a greater percentage increase over the preburn suckering levels than the control showed. The percentage increase in suckering on aspen clones No. 4 and No. 9 never did exceed that on the control; however, suckers on clone No. 4 did number in excess of 30,000 per hectare (12,140 per acre) in the second and third years.

No clear reasons emerge for the differing responses among aspen clones, but conjecture points to several possibilities, including preburn vigor of the clones, density of parent stems, and intensity and completeness of burn. Hopefully, additional analyses will help us assess the effects of those variables.

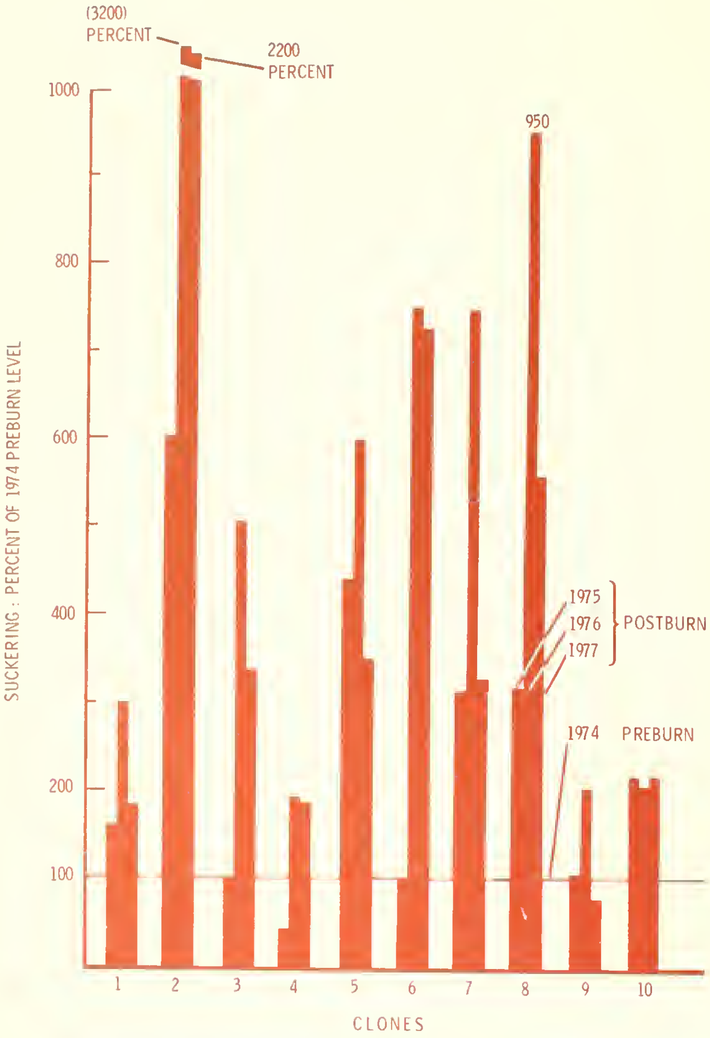

Figure 3.--Postfire aspen suckeri (1975-1977) on nine burned clones and one unburned clone (No.10) expressed as a percentage of preburn (1974) levels.

According to Jones and Trujillo (1975), clonal differences in aspen have been reported for susceptibility to a major decay fungus (Wall 1971), for susceptibility to frost damage (Egeberg 1963), and for suckering ability and optimum conditions for suckering (Barnes 1969, Farmer 1962, Tew 1970). It appears plausible then that genetic variation also may contribute to clonal differences in response to fire; therefore, caution is necessary in interpreting results, for the one control clone (No. 10) may not represent a good standard for comparing results on the nine burned clones.

Sucker numbers on the unburned control increased from a preburn level of 8,500 per hectare (3,440 per acre) to a relatively constant level of approximately 18,600 per hectare (7,527 per acre) in the first three postburn years (fig. 4). The reason for this increase is unknown. On the nine burned clones, average numbers of suckers per clone increased from a preburn 6,200 per hectare (2,509 per acre) to 11,600, 28,000, and 17,200 per hectare (4,694, 11,332, and 6,960 per acre) in the next 3 years. Sucker numbers on all nine aspen clones were greatest 2 years after burning. Although they dropped in the third year, they still exceeded the preburn numbers on all clones except one.

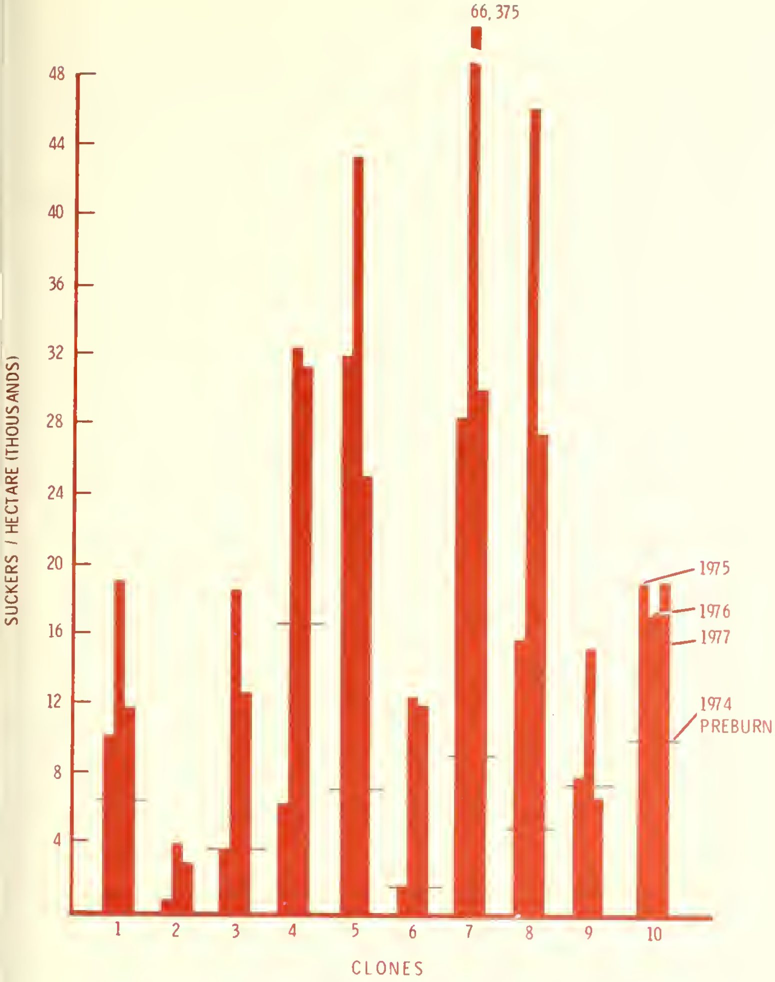

Figure 4.--Aspen suckering before (1974) and after the fire (1975-1977) on nine burned clones and one unburned clone (No. 10).

Overall, sucker numbers on the burned clones increased 178 percent in 3 years, as opposed to 119 percent on the unburned clone. The net effect of burning appeared to be beneficial to suckering.

But numbers alone do not spell success. These aspen stands will regenerate successfully only if a sufficient number of suckers can attain a height at which their leaders are no longer vulnerable to browsing.

The extent of leader damage was determined each spring on eight plots in each clone. Percentage of leaders browsed dropped from a preburn 80 percent to 63, 55, and 32 percent in the next 3 years. This sampling allowed no assessment of year-to-year height changes caused by repeated, alternating cycles of growth and browsing; nor did it yield data on mortality or on utilization of current growth.

Accordingly, 20 suckers per clone were tagged in 1976 for measuring each summer and spring. An additional 20 suckers were tagged in each of three exclosures--two on burned clones (Nos. 4 and 9) and one on the unburned (No. 10) clone. Results of subsequent measurements are shown in table 1.

Table 1.--*Effect of browsing on 20 tagged aspen suckers in each of 10 clones*

Clone	Winter 1976-1977			Height change from summer 1976 to summer 1977	
	Mortality	Utilization current growth	Height reduction from summer	Unprotected	Protected in exclosures
	Percent				
1	5	33	28	14	
2	5	46	33	-6	
3	0	38	24	0	
4	20	68	49	-25	16
5	5	58	37	10	
6	5	63	37	-10	
7	5	17	15	10	
8	0	22	13	4	
9	10	64	34	-20	17
10	15	34	10	14	7
Average	7	44	28	1	13

In the winter of 1976-1977, elk browsed an average 44 percent (range: 17 to 68 percent) of the current growth and reduced the average height of suckers 28 percent. In 1977, tagged suckers had grown to an average height only 1 percent greater than befor browsing the previous year. Average heights decreased (range: 6 to 25 percent) on four clones, increased (range: 4 to 14 percent) on five, and remained unchanged on one clone. During the same period, the average height of suckers in the exclosures increased 17 percent on the burned clones.

Overwinter mortality of tagged suckers subject to browsing was 7 percent. None of the 60 tagged suckers in the exclosures died.

CONCLUSIONS

So, what have we learned?

- Fire is a temporary deterrent to elk use of aspen stands.

- Although fire increases suckering in aspen, the response among clones is highly variable.

Though analyses are not yet completed, preliminary data plottings suggest that we haven't isolated causes of this variation with accuracy having much predictive value.

The variability does suggest that the probability of successful regeneration of aspen stands used by elk would be enhanced by large fires burning many clones, rather than by small fires in one or two isolated stands. Intuition tells us that badly deteriorated stands of low vigor and few parent stems are poor candidates for burning.

- Whether fire is feasible for regenerating aspen stands under current levels of elk browsing remains to be seen.

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FUEL MANAGEMENT OPPORTUNITIES ON THE LOLO NATIONAL FOREST:

AN ECONOMIC ANALYSIS

Donald B. Wood[1]

ABSTRACT

Examines economic feasibility of managing nonslash fuels in mature timber to reduce the costs and damages of wildfire. A 1.2-million-acre (496 000 hectare) study area is stratified by timber value, fire occurrence rate, and fuel hazard. Maximum potential fuel management benefits--based on the elimination of expected class E+ fires--are estimated for each stratum and compared to treatment cost estimates. Concludes that fuel treatment to protect timber alone is not economically feasible, but may be justified if treatment enhances other forest values such as wildlife habitat, livestock forage, etc.

KEYWORDS: forest fuels, fire management, hazard reduction, fuel management

Reducing fire hazard by treating fuels is frequently proposed as a means of reducing the acreage burned by wildfire. Although fuel management could certainly curtail wildfire, whether and under what conditions benefits will exceed costs is essentially unknown. Consequently, the extent to which fuel management can be depended upon to solve present and future fire problems is uncertain. This report assesses whether fuel treatment is an economically feasible fire management tool. Results should contribute toward decisions involving the implementation of fuel management programs.

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The study was conducted on the Lolo National Forest in Montana and was limited to analyzing the treatment of nonslash fuels in mature timber. The overall objective was to estimate the acreage of mature timber stands that could reasonably be expected to yield fuel management benefits greater than or equal to treatment costs. Benefits considered were averted damages to timber and other forest commodities and reductions in suppression and rehabilitation costs.

Timber, suppression, and rehabilitation benefits were estimated using methods derived in a previous study (Wood 1978). (Methods are described in the following section.) Treatment impacts on nontimber commodities such as recreation and wildlife were considered indirectly. The value of nontimber outputs required to meet any portion of treatment costs not covered by timber, suppression, and rehabilitation benefits was determined and judged to be either reasonable or unreasonable. Treatment costs are based on estimates extracted from the literature.

Estimating Benefits

Benefit estimates are based on the assumption that fuel management will result in maximum response--defined as the elimination of fires greater than 300 acres (121.5 hectares) (Class E+ fires). In the Northern Region, these large fires account for more than 80 percent of the acres burned and most of the fire damage. Because the location and timing of future Class E+ fires are unknown, the approach is based on probabilities, and benefits are expressed in averages or expected values.

Fifteen years of Northern Region fire records were used as a basis for estimating expected Class E+ acres burned. Examination of these records revealed that the proportion of fires reaching Class E+ size was directly related to the spread rate component of "fuel type at point of origin." During the period examined, the percentages of fires escaping to Class E+ size according to this variable were: low, 0.203 percent; medium, 0.428 percent; high, 0.774 percent; and extreme, 5.739 percent. The percentages provide the basis for estimating acres saved annually. The fuel type of the analyzed stand determines the appropriate percentage which (in decimal form) is multiplied by the average number of fires expected annually. The result, expected annual Class E+ fires, is multiplied by mean Class E+ fire size (2,022 acres, 818.9 hectares) giving expected annual Class E+ acres burned--and an estimate of annual acres saved.

Total acres saved is derived by multiplying annual acres saved by the number of fire seasons encompassed by treatment and harvest. It is assumed that the first fire season immediately follows treatment and the stand is harvested after the fire season of the scheduled harvest year. As a result, the number of fire seasons is one greater than the number of full years between treatment and harvest. For computational purposes, if a stand is to be harvested in T years, one benefit increment is assumed to occur at the beginning of the first year and one at the end of each of the ensuing T years.

Benefits due to increased harvest receipts are determined by multiplying total acres saved by estimated stumpage value per acre and discounting the result to present value. The present value of any timber that would have been salvaged is deducted to give net timber benefits.

Burned timber is assumed salvaged in the year it burns. Because the discounting period and volume per acre change each year, present values are independently computed year by year and then added to yield total salvage value. This step is deleted if burned timber is not salvaged.

Finally, suppression and rehabilitation cost savings are estimated. Annual savings are determined by multiplying annual acres saved by per acre costs derived from historic cost data ($230 per Class E+ acre burned). The annual costs are then discounted to present value.

The present value of fuel management benefits is dependent on the length of time between treatment and harvest (T). As time between treatment and harvest increases, benefits initially increase but typically peak and decline as a result of discounting. The value of an acre saved declines by a factor of $(1 + i)^{-1}$ (i = interest rate) each year T is extended. After some point, the reduction in per acre value will exceed the positive impact of saving additional acres from burning and total benefits will decline. As additional years are added, this divergence will increase and the decline in present value will accelerate. At current 7 to 10 percent interest rates, benefits typically peak within 15 years of harvest.

The procedures discussed are summarized in the equation:

$$F = (T + 1)\ bh(1 + i)^{-T} - \sum_{t} bs_{t}(1 + i)^{-t} + \sum_{t} bc(1 + i)^{-t}$$

Where: F = present value of fuel management benefits;

T = total years between treatment and harvest;

t = years elapsed since treatment;

b = annual expected Class E+ acres saved;

h = per acre harvest value;

s_t = per acre salvage value in year t;

c = per acre suppression and rehabilitation costs.

The first term represents the value of additional live timber harvested; the second, salvage value foregone; and the third, suppression and rehabilitation cost savings. In the ensuing discussion, fuel management benefits have been converted to "benefits per acre protected" by dividing stand benefits by their respective acreages.

METHODS

Study Area

An area of 1.2 million acres (486 000 hectares), approximately two-thirds of the Lolo National Forest, was selected for the study. The remaining one-third (Ninemile and Superior Ranger Districts) was eliminated due to data deficiencies. Evaluating all mature stands within the study area would have been arduous and costly. Instead, only stands representative of the highest treatment benefits available were selected. Previous experience had shown that the highest benefits resulted from mature stands having high and extreme fuel types and fire occurrence rates greater than 0.5 annual ignitions per 10,000 acres (4 050 hectares).

Because young and unstocked stands were not considered, the study may not encompass all economically feasible fuel management opportunities. Benefits for such stands are typically low due to long discounting periods. In some cases, however, the risk of fire spreading to adjacent mature stands may significantly increase treatment benefits.

Data Collection

The data used to provide physical stand variables were available in various forms. Other information, however, had to be estimated:

1. Harvest dates were known only for stands scheduled for harvest within 5 years.

2. Future stumpage values were unknown.

3. The extent of salvageable burned timber was unknown.

Estimates were based on maximizing fuel management benefits.

Resultant assumptions are as follows:

1. Stands will be harvested in the number of years required to maximize fuel management benefits.

2. Stumpage prices are assumed to be $180 per thousand board feet. This is almost $27 higher than the maximum average stumpage price on the Northern Region for any species within the last 10 years (Western White Pine: 1977 price $153.14 per M bd. ft.).

3. Only timber burned in the year of harvest will be salvaged.

With this approach, the estimated benefits indicate the maximum fuel management expenditure that can be justified without considering nontimber values.

Fuel maps showing rate of spread and resistance to control were available for the study area. Fuel types having high and extreme spread rates were traced on overlays.

Fire occurrences were plotted for the period beginning in 1950. Boundaries were drawn around areas having relatively homogeneous occurrence rates. Subdivisions with similar rates were then combined to form five occurrence zones and an average rate for each zone was calculated. The five zones were:

Zone	Annual fires per 10,000 acres
1	0.735
2	0.901
3	1.180
4	2.683
5	3.646

Having identified areas meeting the minimum criteria for hazard and occurrence rate, individually, areas fulfilling both requirements were identified by combining fuel type and occurrence rate maps and marking the overlap on map overlays.

The third step was to outline areas meeting the first two criteria that contained mature timber stands, with the aid of Forest Service aerial photograph interpretation (P.I.) maps. Although P.I. maps indicate whether stands are mature, they do not provide information on timber species, age, or volume. Instead, stands were classified by habitat type, then volumes were determined from yield tables for habitat types on the Lolo National Forest. Because stand ages were unknown, the average yield for mature stands of all ages was computed for each habitat type. The per acre volumes for the four types recorded were: 5.762 M bd. ft., 8.351 M bd. ft., 9.604 M bd. ft., and 11.406 M bd. ft. Multiplying by $180 yielded per acre values--$1,037, $1,503, $1,729, and $2,053, respectively--that were subsequently used to determine fuel treatment benefits.

Stands having similar fuel hazards, occurrence rates, and timber values were combined and per acre benefits were computed for each resulting stand category. The reader should recognize that benefits for stands within a category could vary somewhat from computed values because of differences in surrounding areas. A Class E+ fire in any one of the stands would probably spread to surrounding areas and the benefit of preventing the fire would depend partially on the values of adjacent stands. Stands surrounded by higher value areas will yield greater benefits than those surrounded by less valuable areas. Results computed for a category must therefore be interpreted as falling within a range of benefits exhibited by stands within that category.

RESULTS AND DISCUSSION

Of the 1.2 million acres (486 000 hectares) examined, 25,655 acres (10 390 hectares) (2.14 percent) met criteria for evaluation (high- or extreme-hazard fuel type, occurrence rate greater than 0.5 fires per 10,000 acres (4 050 hectares), and mature timber). The distribution of acreage by value per acre and occurrence zone is shown in table 1 (all acres had a high hazard fuel type). More than 75 percent of the qualified acreage was in the lowest occurrence zone.

Table 1.--*Distribution of evaluated acreage by value per acre and zone*

Zone	Timber value per acre				
	$1,037	$1,503	$1,729	$2,053	Total
	Acres				
1	2,432	843	13,541	1,661	18,477
2	624	513	2,439	1,526	5,102
3	187	125	1,518	107	1,937
4	--	--	--	--	--
5	--	138	--	--	138
Total	3,243	1,619	17,498	3,294	25,654

Benefits per acre-protected for all occurrence-rate/timber-value combinations are given in table 2. Using a 7 percent interest rate, values range from $11.95 to $80.48 per acre; with a 10 percent interest rate, values ranged from $8.77 to $58.87. Average per acre benefits were $17.66 (7 percent) and $12.92 (10 percent).

Table 2.--*Fuel management benefits per acre protected for 7 and 10 percent interest rates*

Occurrence zone	Interest rate	Timber value per acre			
		$1,037	$1,503	$1,729	$2,053
	Percent	*Dollars*			
1	7	11.95	14.81	16.22	18.26
	10	8.77	10.85	11.87	13.33
2	7	14.64	18.16	19.89	22.38
	10	10.74	13.30	14.55	16.34
3	7	19.18	23.78	26.05	29.31
	10	14.07	17.42	19.05	21.40
4	7	--	--	--	--
	10	--	--	--	--
5	7	--	80.48	--	--
	10	--	58.87	--	--

Although fuel treatment costs in uncut stands have not been determined for the Northern Rockies, regional slash treatment costs provide a reasonable estimate. In 1972, the average cost for treating slash by broadcast burning in the Northern Region was $21.54 per acre ($30.83 per acre in 1977 dollars) (Northern Region, USDA Forest Service, 1974). Cooper (1975) estimates that prescribed burning costs in uncut stands in the West range from $1 to $50 per acre, occasionally reaching $100. Thirty dollars an acre, then, is not an unreasonable estimate, considering the risks and difficulties of treating standing timber.

A portion of the study area can be treated with fuelbreaks or fuel mosaics. Wood (1978) estimated that fuelbreaks on 10 percent of an area would cost a minimum of $31 per acre protected. Mosaics could cost less per acre protected, depending on treatment intensity and proportion of area treated. To account for this possible reduction in area treated, cost-per-acre-protected was arbitrarily reduced by one-third to $20 per treatment. If the initial treatment is followed by one additional maintenance treatment after 10 years, the present value of costs becomes approximately $30 for the 7 percent interest rate and $28 for the 10 percent rate. To simplify the following discussion, $30 will be used in both cases to evaluate the relative magnitude of benefits.

Only 138 acres (55.9 hectares) or about one-half of 1 percent of the qualified area produced benefits exceeding $30 for both the 7 and 10 percent cases. For benefits to exceed treatment costs in more than half of the evaluated area, treatment costs would have to be less than $10 per acre protected, again assuming one additional $10 treatment after 10 years. Remember that one-half of the evaluated area is only about 1 percent of the total study area.

Two major factors contribute to the relatively low benefits. First, fire occurrence rates in the evaluated area were, on the average, low. In the one high-occurrence-rate area, benefits were substantial. Second, timber yields are low, even on the best sites. Values per acre are also low even when assuming generous stumpage prices and zero salvage.

Nontimber Benefits

Because nontimber values must be considered in justifying fuel treatment, potential contributions toward the $30 per acre treatment cost were examined. Calculations assume that an acre saved from burning will produce a constant amount of nontimber value annually until the stand is harvested. This does not imply, however, that total annual nontimber benefits accruing to fuel treatment will be constant--cumulative acres saved increases each year. For example, if an average of 1 acre per year is expected to burn in a 1,000-acre stand, 1 acre would be the first-year benefit. This same acre would continue to produce benefits the following year in addition to a second acre saved, doubling the first year benefits. Thus, annual nontimber benefits are an increasing function of years elapsed since treatment. The present value-per-acre-protected can be expressed:

$$V_o = 1/r\ [ab + 2ab(1 + i)^{-1} + 3ab(1 + i)^{-2} + \ldots + (T + 1)\ ab(1 + i)^{-T}]$$

Where: V_o = present value of nontimber outputs per acre protected

r = number of acres protected

a = annual value output of an acre saved from burning

b = annual expected Class E+ acres saved

T = total years between treatment and harvest

i = interest rate

The equation assumes that once an acre is burned, nontimber outputs are lost for the entire period of analysis. By solving the above equation for "a," we can determine the annual output per acre necessary to yield a given or desired level of benefits. The annual nontimber value required to bring benefits to $30 per acre (assuming the same timber values and time periods) was thus determined for the study area. Results of this determination are presented in table 3. Table 4 shows the values required for benefits of $30 per acre protected on the same area where no timber is harvested (suppression and rehabilitation cost savings are still included).

Table 3.--*Annual nontimber benefits required (in addition to timber benefits) to yield benefits of $30 per acre protected*

Occurrence zone	Interest rate	Timber value per acre			
		$1,037	$1,503	$1,729	$2,053
	Percent	- - - - - - - - - - - - *Dollars* - - - - - - - - - - - -			
1	7	184.00	165.32	161.01	137.12
	10	286.47	272.30	273.03	251.04
2	7	127.73	105.12	96.37	72.63
	10	212.01	193.71	189.80	167.81
3	7	68.70	42.17	28.75	5.02
	10	133.89	111.42	102.71	80.67

Table 4.--*Annual per acre, nontimber benefits required to yield benefits of $30 per acre protected when timber value is zero*

Occurrence zone	Interest rate	Period of benefit accumulation	
		20 years	30 years
	Percent	*Dollars*	
1	7	232.46	155.11
	10	326.54	245.64
2	7	189.63	126.54
	10	266.38	200.38
3	7	144.80	96.62
	10	203.40	153.00
5	7	46.86	31.27
	10	65.82	49.52

The tabulated figures are based on the following assumptions: (1) burned acres do not regain the capacity to produce nontimber benefits until the scheduled harvest date, or for 20 or 30 years if timber is not harvested and (2) fuel management will be totally effective in eliminating Class E+ fires. If either assumption is discounted annual output value would have to be increased to cover treatment costs.

To what extent can nontimber values on the Lolo National Forest defray protection costs? Clawson (1976) estimates that the average annual gross value (including timber) produced by the National Forest System is $6.63 per acre. Most of the nontimber benefits required are several hundred percent higher (tables 2, 3). The difference would be even more pronounced if management costs were deducted. This does not mean that these values are unattainable, but unless Clawson's figures are grossly low, values of this magnitude would be unusual and would occur only in areas of high recreational use and development, outstanding esthetic quality, endangered species habitat, and similar areas. The implication for the Lolo National Forest is that nontimber resources are unlikely to materially increase the acreage that can be economically treated.

Forest values must be high because the acreage saved is small relative to the number of acres treated or protected. For example, treating a 1,000-acre stand with a high-fuel hazard and an occurrence rate of one fire per 10,000 acres per year would result in an average of about 1.5 acres saved per year. If treatment benefits extend 20 years, an average of 30 acres would be saved. The present value of the benefits produced by the 30 acres must be divided by 1,000 to determine benefits per acre protected.

The treatment itself may do more to increase wildland values than the reduction of fire danger. For example, treating fuels by prescribed fire could result in increased forage production. In the above example, only 30 acres produced benefits as a result of Class E+ wildfire elimination; as a result of increased forage productio all 1,000 acres might produce benefits.

CONCLUSIONS

Timber saved, and savings in costs of fire suppression, and costs of rehabilitation, would rarely exceed costs of fuel treatment on the Lolo National Forest. This conclusion holds even under the most optimistic comparisons of costs and benefits.

Protecting nontimber values will not improve the economic feasibility of fuel management. Considering the low probability of fire, nontimber values would have to be very high to significantly defray treatment costs.

Fuel management may be feasible in areas holding unusually high timber values or nontimber values (or both), or where treatment costs are much lower than hypothesized here. Fuel management may also be feasible when it enhances--not merely protects--nontimber values such as wildlife habitat, livestock forage, recreation, and so on.

Conclusions of this study may not apply to other forests in the Northern Rockies nor forests in other regions. The conclusions hold true for most of the Northern Rockies where mature timber stands generally produce low yields. Fuel treatment may be feasible in parts of the Pacific Northwest where old-growth stands attain high volumes and values. Fuel hazards and rates of fire occurrence would have to be at least as severe as those found on the study area.

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Research Note

USDA FOREST SERVICE INT-273
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PARMS -- A Computer Program to Modify FINSYS-2 TABLE-2 and Other FORTRAN Programs

Terrence Throssell[1]

ABSTRACT

Presents a method for reducing the core size requirements of FINSYS-2 TABLE-2 and other FORTRAN programs. Describes the use of a preprocessor to get information about the size requirements of a particular job and how to incorporate this information into producing a tailor made executable program.

KEYWORDS: computers, FORTRAN, FINSYS-2 TABLE-2, dimension modification

INTRODUCTION

In the late 1960's a standard version of the FORTRAN program TABLE was published as a portion of the general inventory data reduction system FINSYS[2]. Documentation explained how to modify the dimensions of the standard version to meet each user's special applications.

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[2] Wilson, R. W., and R. C. Peters. 1967. The Northeastern Forest Inventory Data Processing System, USDA For. Serv. Res. Pap. NE-61 and NE-70 to 78. Northeastern For. Exp. Stn., Broomall, Pa.

It soon became apparent, however, that most users often needed to modify the program dimensions. Some users enlarged the dimensions to increase the work capabilities of the program while other users cut back its size to run on computers with limited storage. Experienced users spent much time calculating required dimension limits and modifying the program accordingly. Inexperienced users made frustrating mistakes.

Then, in the early 1970's, a solution was proposed in the form of a computer program, PARMS. This program has since been refined to run with the latest version of FINSYS-2 TABLE-2 being used by the Forest Service and cooperators on present generation computers. PARMS eliminates the need for programers to make dimension modifications in the FORTRAN program FINSYS-2 TABLE-2. PARMS not only saves programer time, but also utilizes computer storage more efficiently. Futhermore, the general method used by PARMS can be applied to other FORTRAN programs.

PARMS METHOD

The general PARMS method has two requirements: (1) the FORTRAN program must be structured so that all dimension changes can be made in the main calling routine, and (2) the main calling routine must be short, 25 lines or less.

Most FORTRAN programs already meet the first requirements; few meet the second. But generally little work is required to split a long main routine into a shorter main routine with a long control subroutine. If these two requirements are met, it becomes very easy to modify dimensioned space in a FORTRAN program. One need only replace the main routine with another written to the required dimension limits.

The rewriting and replacing of the main routine can either be done manually by a programer or it can be done automatically by the computer. Consider the simple main routine in figure 1. To modify the dimension limits of arrays A, B, and C from 5000, 10000, and 25000 to 3000, 5000, and 2000 as in figure 2, only six numbers need to be changed. These changes can easily be made by the computer. Figure 3 shows a computer program, the method used by PARMS, to accomplish the task. The program reads the dimension limits punched on a data card and writes the new FORTRAN main routine on logical unit 8, a scratch file. Job control language handles the task of replacing the old main routine with the new one.

Job control language varies greatly from one computer to another. Figure 4 shows the processing flow for a regular FORTRAN program. Figure 5 shows the same program setup under the PARMS method. In each diagram, dotted lines show that portion of the processing that is transparent to the user. To the user the only difference in the PARMS method is that it does not require the input main FORTRAN routine but does require input dimension limits.

In review, PARMS can be applied to FORTRAN programs with short main calling routines structured to facilitate dimension modification. A program and associated job control language can be written to automate the rewriting and replacing of this main routine with another routine written to the desired dimension limits.

```
      DIMENSION A( 5000),B(10000),C(25000)
      DATA I,J,K/ 5000,10000,25000/
      CALL CONTRL(A,B,C,I,J,K)
      STOP
      END
```

Figure 1.--Sample FORTRAN main routine

```
      DIMENSION A( 3000),B( 5000),C( 2000)
      DATA I,J,K/ 3000, 5000, 2000/
      CALL CONTRL(A,B,C,I,J,K)
      STOP
      END
```

Figure 2.--Same routine as figure 1 but with modified dimension limits

```
      DATA LU5,LUOUT/ 5,8/
      READ(LU5,5) I,J,K
    5 FORMAT(3I5)
      REWIND LUOUT
      WRITE(LUOUT,10) I,J,K
   10 FORMAT(6X,'DIMENSION A(', I5, '),B(', I5, '),C(', I5, ')' )
      WRITE(LUOUT,20) I,J,K
   20 FORMAT(6X,'DATA I,J,K/', I5, ',', I5, ',', I5, '/' )
      WRITE(LUOUT,30)
   30 FORMAT(6X,'CALL CONTRL(A,B,C,I,J,K)',/,6X,'STOP',/,6X,'END')
      END FILE LUOUT
      REWIND LUOUT
      STOP
      END
```

Figure 3.--FORTRAN program to write the main routines shown in figures 1 and 2

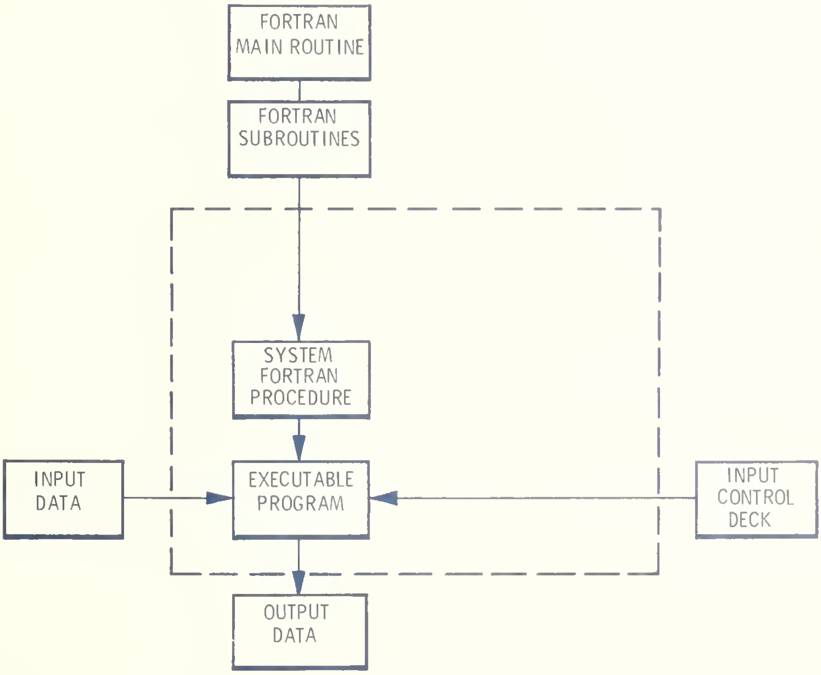

Figure 4.--Regular FORTRAN program processing flow.

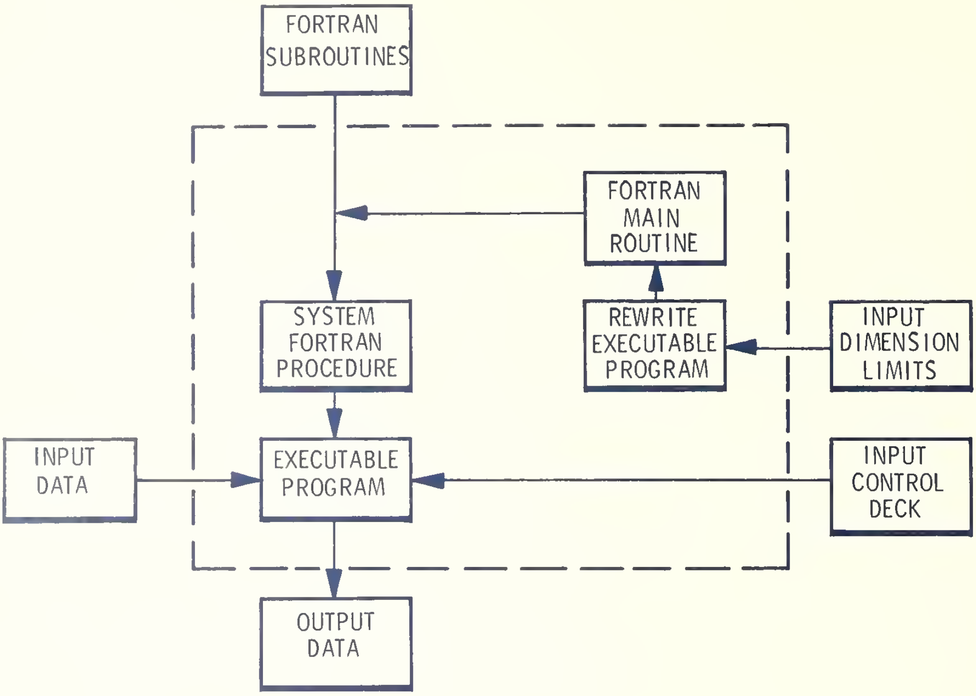

Figure 5.--Generalized method processing flow.

PARMS AND FINSYS-2 TABLE-2

PARMS was written especially for the FORTRAN program FINSYS-2 TABLE-2. The processing flow for PARMS as shown in figure 6 varies slightly from that of the general method shown in figure 5. The difference is that PARMS does not require a separate input for the dimension limits; the TABLE-2 Job Control Deck already contains this information. PARMS reads the control deck and tabulates such items as the number of input tables, the number of output tables, the size of each defined table, plus various other processing options. From this information, PARMS determines the dimension limits necessary to run the input control deck.

Unlike the FORTRAN program shown in figure 3, PARMS can recover from bad input. If PARMS is unable to determine any dimension limit due to errors in the TABLE-2 Job Control Deck, it reacts by substituting a set of default dimension limits. In this manner, PARMS always creates an executable TABLE-2 program. It is not the responsibility of PARMS to flag errors in the TABLE-2 Job Control Deck; that responsibility rests with the TABLE-2 program.

COMMENTS

The general PARMS method makes it much easier to modify dimensioned space in a FORTRAN program, and PARMS can be applied to widely different computer systems. In the case of FINSYS-2 TABLE-2, PARMS totally eliminates the need for programers to make any modifications. Another advantage is that it produces more core efficient programs. By cutting dimension limits to the bare minimum, PARMS insures the most core efficient FINSYS-2 TABLE-2 programs.

A slight disadvantage to the PARMS method is the extra computer time it takes to create and use the new main routine in forming the executable program. The cost of this computer time, however, generally is insignificant compared to a programer's time.

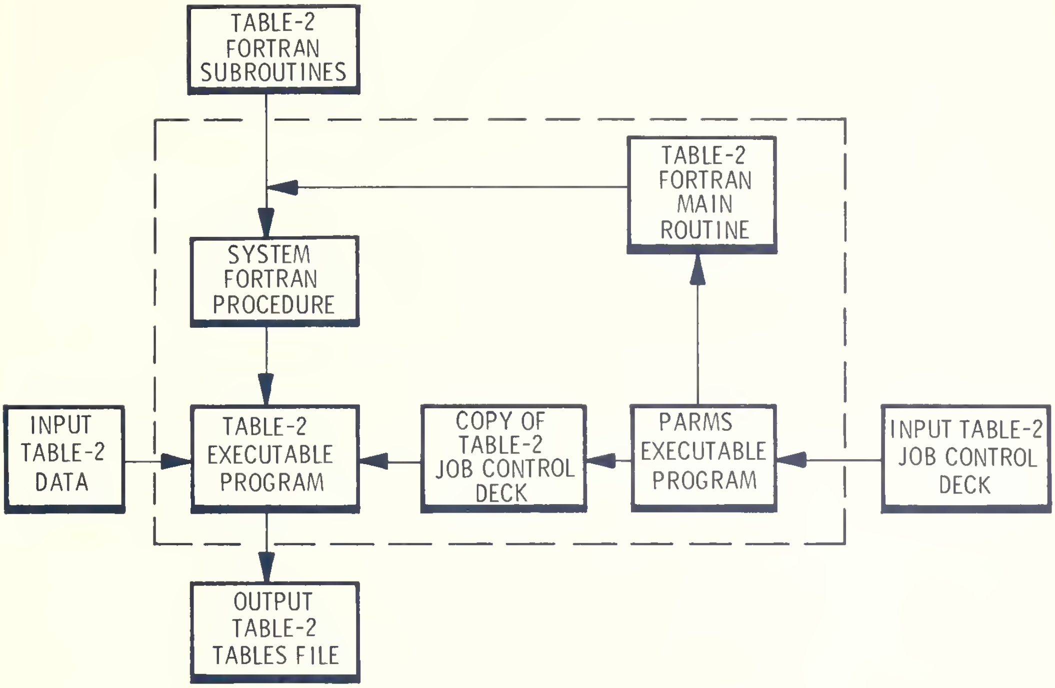

Figure 6.--PARMS processing flow.

APPENDIX A

Caution on FORTRAN Program Structure

Although most FORTRAN programs and subroutines are already structured to facilitate the use of PARMS, two caution notes are in order.

1. Use of common blocks is explicitly forbidden. All arrays that may have dimension changes must be passed as arguments in calls to the subroutines that use them.

2. Variable dimensioning must be consistent among all routines referencing a given array.

Example:

```
CALL SUB1 (X,10,10)

.

.

.
SUBROUTINE SUB1(X,M,N,)

DIMENSION X(M,N)

.

.

.

CALL SUB2(X,5,10)
```

The above call would cause disastrous realignment of the array X.

APPENDIX B

Job Control Language Examples.

Examples of the job control language required for PARMS are shown for the CDC CYBER, IBM, and UNIVAC computers. All examples assume that the FORTRAN program PARMS is stored in executable form, and that the FINSYS-2 TABLE-2 program is stored in either source, relocatable, or executable form, on the given host computer.

An explanation of the 14 lines of figure 7:

```
 1:GET,PARMS.
 2:GET,TAPE60=T1.
 3:PARMS.
 4:GET,TABSUBS.
 5:GET,CALCUL=T2.
 6:REWIND,TAPE8,TABSUBS,CALCUL,Z.
 7:COPYCR,TAPE8,Z.
 8:COPYCR,TABSUBS,Z.
 9:COPYCR,CALCUL,Z.
10:PACK,Z.
11:FTN,I=Z,L=0.
12:ATTACH,TAPE1=T3.
13:DEFINE,TAPE2=T4.
14:LGO(,OUT995).
```

Figure 7.--CDC CYBER job control language for PARMS

The files named PARMS, TABSUBS, T1, T2, T3, and T4 must already be catalogued on the system. Files TAPE8, TAPE9, Z, and OUT995 are temporary.

FILE NAME	DESCRIPTION
PARMS	EXECUTABLE PROGRAM PARMS
TABSUBS	SOURCE FOR TABLE-2 SUBROUTINES
T1	TABLE-2 JOB CONTROL DECK
T2	SOURCE FOR SUBROUTINE CALCUL
T3	INPUT TABLE-2 DATA
T4	OUTPUT TABLE-2 TABLES FILE

Lines 1-3	Execute program PARMS. Read the TABLE-2 Job Control Deck from unit 60 and copy it to temporary unit 9 (not shown). Write the new main routine on temporary unit 8.
Lines 4-10	Build a temporary source file of the new main routine, the new subroutine CALCUL, and the standard TABLE-2 subroutines.
Line 11	Compile the TABLE-2 program from the temporary new source file.

Lines 12-14 Create and execute the new temporary TABLE-2 program. Read the Job Control Deck from temporary unit 9 (not shown). Read the input data from unit 1 and write the output tables file on unit 2. Direct the print to the temporary file named OUT995 for later disposition.

An explanation of the 28 lines of figure 8:

```
 1://CALCUL   EXEC PGM=COPY
 2://STEPLIB  DD DSNAME=FST.PGMLIB,DISP=SHR
 3://FT02F001 DD DSNAME=&&CALCUL,UNIT=WORK,SPACE=(80,(1000,100)),          X
 4://            DISP=(NEW,PASS),DCB=BLKSIZE=80
 5://FT01F001 DD *
 6:     TABLE-2 USER MODIFIABLE FORTRAN SUBROUTINE CALCUL
 7:/*
 8://PARMS    EXEC PGM=PARMS
 9://STEPLIB  DD DSNAME=FST.PGMLIB,DISP=SHR
10://FT06F001 DD SYSOUT=E
11://FT08F001 DD DSNAME=&&MAIN,UNIT=WORK,SPACE=(80,(100,100)),             X
12://            DISP=(NEW,PASS),DCB=BLKSIZE=80
13://FT09F001 DD DSNAME=&&DECK,UNIT=WORK,SPACE=(80,(1000,100)),            X
14://            DISP=(NEW,PASS),DCB=BLKSIZE=80
15://FT05F001 DD *
16:     TABLE-2 JOB CONTROL DECK
17:/*
18://TABLE    EXEC FORTGCLG
19://FORT.SYSIN DD DSNAME=&&MAIN,DISP=(OLD,DELETE)
20://           DD DSNAME=&&CALCUL,DISP=(OLD,DELETE)
21://LKED.OLDLOAD DD DSNAME=FST.PGMLIB,DISP=SHR
22://LKED.SYSIN DD *
23: INCLUDE OLDLOAD(TABLE)
24: ENTRY MAIN
25:/*
26://GO.FT05F001 DD DSNAME=&&DECK,DISP=(OLD,DELETE)
27://FT01F001 DD (INPUT TABLE-2 DATA FILE DEFINITION)
28://FT02F001 DD (OUTPUT TABLE-2 TABLES FILE DEFINITION)
```

Figure 8.--IBM job control language for PARMS

Executable programs COPY, PARMS, and TABLE must be catalogued on the system. Data sets &&MAIN, &&DECK, and &&CALCUL are temporary.

Lines 1-7 Copy FORTRAN source statements for subroutine CALCUL to a temporary file for later use in compiling the TABLE-2 program.

Lines 8-17 Execute program PARMS. Read the TABLE-2 Job Control Deck as card input. Copy the control deck to the temporary unit 9. Write the new main routine on temporary unit 8.

Lines 18-20	Compile the new main routine and new subroutine CALCUL.
Lines 21-25	Create the executable TABLE-2 program from the new object main routine, the new object subroutine CALCUL, and the old load module of the standard TABLE-2 program stored in program library FST.PGMLIB.
Lines 26-28	Execute the new TABLE-2 program. Read the control deck from the copied temporary file. Read the input data from unit 1. Write the output tables file on unit 2.

An explanation of the 21 lines of figure 9:

```
 1:@FOR,IS CALCUL
 2:      TABLE-2 USER MODIFIABLE FORTRAN SUBROUTINE CALCUL
 3:@ASG,T 3.
 4:@ASG,T 4.
 5:@ASG,T 9.
 6:@XQT PARMS
 7:      TABLE-2 JOB CONTROL DECK
 8:@EOF
 9:@FOR,IS MAIN
10:      TABLE-2 FORTRAN MAIN ROUTINE BEGINNING STATEMENTS
11:@ADD 4.
12:      TABLE-2 FORTRAN MAIN ROUTINE ENDING STATEMENTS
13:@MAP,INX      ,TPF$.TABLE
14: IN TPF$.MAIN,.CALCUL
15: IN TABLIB.SUB1,.SUB2,.VARIAN
16:@ADD 3.
17:@ASG,OPTIONS NAME1.   . (INPUT TABLE-2 DATA FILE)
18:@USE 10.,NAME1.
19:@ASG,OPTIONS NAME2.   . (OUTPUT TABLE-2 TABLES FILE)
20:@USE 2.,NAME2.
21:@XQT TABLE
```

Figure 9.--UNIVAC job control language for PARMS

Executable program PARMS and the relocatable subroutine for TABLE-2 must be catalogued on the system.

Lines 1-2	Compile subroutine CALCUL.
Lines 3-8	Assign files for and execute program PARMS. Read the Table-2 Job Control Deck from the card reader and write the copy on temporary unit 9. Write the dimension parameters for the new main routine on temporary unit 4. Write the extended storage map collector statements on temporary unit 3.

Lines 9-12	Compile the new main routine using the dimension parameters passed from PARMS on unit 4.
Lines 13-16	Create the executable TABLE-2 program from the new relocatable main routine, the new relocatable CALCUL subroutine, the old relocatable subroutines found in the program library TABLIB, and the extended storage map collector statements passed from PARMS on unit 4.
Lines 17-21	Execute the TABLE-2 Program. Read the Job Control Deck from unit 9. Read the input data from unit 10. Write the output tables file on unit 2.

APPENDIX C

Program PARMS Source Decks

The program consists of the main routine PARMS and subroutines PDPMAP and TABFOR. Subroutine PDPMAP is used only by the UNIVAC version. Subroutine TABFOR is used by the CDC and IBM versions and can be used in place of subroutine PDPMAP for the UNIVAC version.

The value of ISYS will vary with specific machines: ISYS must be set at 0 for the IBM, 1 for the UNIVAC, and 2 for the CDC. For the CDC version, the end-of-file read check must be modified.

PARMS source decks and listings are available from the Intermountain Forest and Range Experiment Station, Ogden, Utah.

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November 1979

ESTIMATING PINYON AND JUNIPER FUEL AND BIOMASS FROM AERIAL PHOTOGRAPHS

Richard O. Meeuwig, Elwood L. Miller, and Jerry D. Budy[1]

ABSTRACT

Regression equations were developed for estimating mass of various fuel components per unit crown area of singleleaf pinyon (Pinus monophylla) *and Utah juniper* (Juniperus osteosperma). *Techniques are described for using these equations for estimating fuel loading, fuelwood volumes, and potential slash production from aerial photographs.*

KEYWORDS: pinyon, juniper, forest fuel, sampling methods, tree biomass.

The singleleaf pinyon-Utah juniper woodland type occupies about 7 million hectares (17 million acres) in the Great Basin. Little information is presently available on the fuel-loading and biomass characteristics of the type. Information on fuel loading (weight per unit area) is needed for predicting fire behavior (Albini 1976). Information is also needed on how much wood is available for fuelwood and other uses and how much slash would be produced by harvesting operations.

---

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Accurate determination of biomass and fuel loading requires on-the-ground measurements, but approximations can be made from aerial photographs. Techniques for estimating loading of various fuel size classes from aerial photographs are presented in this Research Note. These techniques are based on regression equations relating mass per unit crown area to maximum crown diameter. Because of the shrubby form of pinyon and juniper, crown area and crown diameter are the only tree dimensions that can be estimated with confidence on aerial photographs.

PAST WORK

Other than the preliminary work by Moessner (1962), there are no publications on the use of aerial photographs in the pinyon-juniper type; however, as a part of Project Flambeau, Storey (1969) weighed 26 pinyon trees and 16 juniper trees near Lee Vining, California. He found that maximum crown diameter was the best single parameter for estimating both aboveground and root biomass of Utah juniper, and for estimating root biomass of singleleaf pinyon. Stem diameter (1 foot [30 cm] above the ground) was slightly better than maximum crown diameter for estimating aboveground biomass of pinyon. His results show that crown measurements alone may be used to estimate biomass.

METHODS

The regression equations were derived from data obtained by felling, sectioning, and weighing 72 singleleaf pinyon and 33 Utah juniper on selected sites across Nevada. Each of these trees was separated into deadwood and three size classes of live material and then weighed. The three size classes, based on diameter outside bark, were: larger than 3 inches (76 mm), smaller than 1 inch (25 mm), and between 1 and 3 inches. About 10 percent of the less than 1-inch class was subsampled to determine green weights of foliage, twigs smaller than 1/4-inch (6.4 mm), and branches between 1/4- and 1-inch diameter. All sizes of deadwood were weighed together, but the size distribution of deadwood was estimated at the time of weighing. Samples of all size classes from each tree were ovendried at 95° C to determine moisture content.

Depth of litter and duff under the crown of each tree was measured at a point that appeared to represent average depth. Bulk samples of litter (including duff) were taken under four pinyons and three junipers, and ovendried. The apparent densities were 0.091 ± 0.0014 g/cc for pinyon and 0.111 ± 0.005 g/cc for juniper. Under crown fuel loading (kg/m^2) of litter and duff was estimated by multiplying litter and duff depth (cm) by 0.9 kg/m^2/cm for pinyon and 1.1 kg/m^2/cm for juniper. In both species, virtually all litter accumulation occurs under the crowns.

Ovendry mass of the following fuel categories or size fractions (deadwood included) was calculated for regression analysis:

1. Needles or scales (foliage).
2. Twigs smaller than 1/4-inch diameter.
3. Foliage + twigs smaller than 1/4-inch diameter = fine fuels.
4. Twigs and branches larger than 1/4-inch and smaller than 1-inch diameter.
5. Fine fuels + fuels 1/4 to 1 inch = fuels smaller than 1 inch.
6. Stems and branches larger than 1 inch and smaller than 3 inches.
7. Stems and branches smaller than 1 inch + those 1 to 3 inches = stems and branches smaller than 3 inches.
8. Stems and branches larger than 3 inches.
9. Total aboveground biomass: Stems and branches smaller than 3 inches + those larger than 3 inches = total.
10. Litter and duff.

ANALYSIS AND RESULTS

Regression equations were computed for each of the 10 categories for pinyon and juniper. In addition, regression equations were computed for foliage, fine fuels, and litter with pinyon and juniper combined. In all cases, the dependent variable (y) was mass divided by crown area (kg/m^2). Means, standard deviations, and coefficients of variation (CV%) of the dependent variables are tabulated in table 1.

Table 1.--*Equations for estimating mass of fuel components per unit crown area of singleleaf pinyon and Utah juniper. Means ($\bar{y}$), standard deviations (Std. dev.), coefficients of variation (CV%), standard deviations from regression (SDR), and coefficients of variation from regression (CVR%) are listed with each regression equation*

y^1	Species	$\bar{y}$	Std. dev.	CV%	SDR	CVR%	Regression equation
Foliage/Ca	P	2.15	0.661	30.7	0.639	29.7	$\hat{y} = 0.351x - 0.0272x^2 + 1.21$
	J	2.77	0.787	28.5	0.781	28.2	$y = 0.438x - 0.0428x^2 + 1.81$
	P&J	2.35	0.755	32.2	0.736	31.4	$y = 0.339x - 0.0289x^2 + 1.51$
<1/4 inch/Ca	P	1.57	0.498	31.8	0.464	29.6	$y = 3.088x^{\frac{1}{2}} - 0.645x - 1.96$
	J	0.71	0.275	38.6	--	--	$y = \bar{y} = 0.71$
Fine Fuels/Ca	P	3.72	1.040	28.0	0.979	26.3	$y = 0.681x - 0.0530x^2 + 1.90$
	J	3.48	0.996	28.6	0.987	24.4	$y = 0.579x - 0.0557x^2 + 2.19$
	P&J	3.64	1.028	28.2	0.983	27.0	$y = 0.606x - 0.0489x^2 + 2.07$
1/4 to 1 inch/Ca	P	1.50	0.663	44.0	0.562	37.3	$y = 4.493x^{\frac{1}{2}} - 0.852x - 4.06$
	J	1.14	0.453	39.7	0.413	36.2	$\hat{y} = 0.412x - 0.0299x^2 - 0.02$
<1 inch^2/Ca	P	5.21	1.452	27.9	1.265	24.3	$y = 4.074x^{\frac{1}{2}} - 0.0591x^2 - 1.94$
	J	4.62	1.339	29.0	1.314	28.4	$\hat{y} = 0.991x - 0.0856x^2 + 2.17$
1 to 3 inches/Ca	P	2.67	1.449	54.3	0.999	37.4	$\hat{y} = 1.358x - 0.0780x^2 - 1.85$
	J	1.84	0.767	41.7	0.602	32.7	$y = 5.756x^{\frac{1}{2}} - 1.073x - 5.35$
<3 inches/Ca	P	7.87	2.554	32.5	1.916	24.3	$\hat{y} = 8.305x^{\frac{1}{2}} - 0.1000x^2 - 7.35$
	J	6.46	1.958	30.3	1.831	28.4	$y = 1.820x - 0.1422x^2 + 1.57$
>3 inches/Ca	P	6.92	5.939	85.8	4.493	64.9	$y = 1.680x - 1.78$
	J	2.87	1.733	60.4	1.312	45.8	$y = 0.0520x^2 + 1.53$
Total/Ca	P	14.79	7.756	52.4	5.794	39.2	$\hat{y} = 10.46x^{\frac{1}{2}} - 8.44$
	J	9.33	3.216	34.5	2.803	30.0	$y = 3.774x^{\frac{1}{2}} + 1.30$
Litter/Ca	P	5.40	3.628	67.1	2.440	45.2	$\hat{y} = 2.227x - 0.0878x^2 - 3.30$
	J	5.12	3.369	65.8	2.209	43.1	$y = 1.315x - 1.06$
	P&J	5.32	3.535	66.5	2.362	44.4	$\hat{y} = 2.087x - 0.0754x^2 - 2.90$

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[1] y = fuel mass/crown area (kg/m^2); Ca = crown area (m^2); x = maximum crown diameter (m); P = pinyon (72 observations); J = juniper (33 observations); P&J = pinyon and juniper combined (105 observations).

[2] One inch = 25 mm.

The following model was used in all regression analysis:

$$\hat{y} = a + bx + cx^{\frac{1}{2}} + dx^{2}$$

in which x is maximum crown diameter.

In the final equations (table 1), only those terms contributing to minimum standard deviation from regression (SDR) have been retained. In every case, at least one term was superfluous. Two terms provided the smallest SDR in most cases. For juniper twigs smaller than 1/4 inch, the mean value (0.71 kg/m^2) provides the best estimate because none of the terms reduced the SDR below the standard deviation.

Coefficient of variation from regression (CVR%) is analogous to coefficient of variation (CV%), being the standard deviation from regression expressed as a percentage of the mean (Draper and Smith 1966, p. 119). The coefficient of variation (CV%) provides an indication of the error to be expected if the mean ($\bar{y}$) is used for estimation and CVR% provides an indication of the error to be expected if the regression equation is used. Comparison of CV% with CVR% shows about how much the accuracy of estimation can be improved by use of regression.

Foliage mass per unit crown area is about the same at all crown sizes (fig. 1) and little is gained by regression; the means are nearly as accurate as the regression equations. The relation between fine fuels per unit crown area and crown diameter is a little more pronounced than that for foliage alone. Juniper tends to have more foliage mass per unit crown area than pinyon, but pinyon has more twig mass, resulting in greater fine fuel mass per unit crown area for pinyon. Except for foliage, pinyon has more mass per unit crown area than juniper in all size classes.

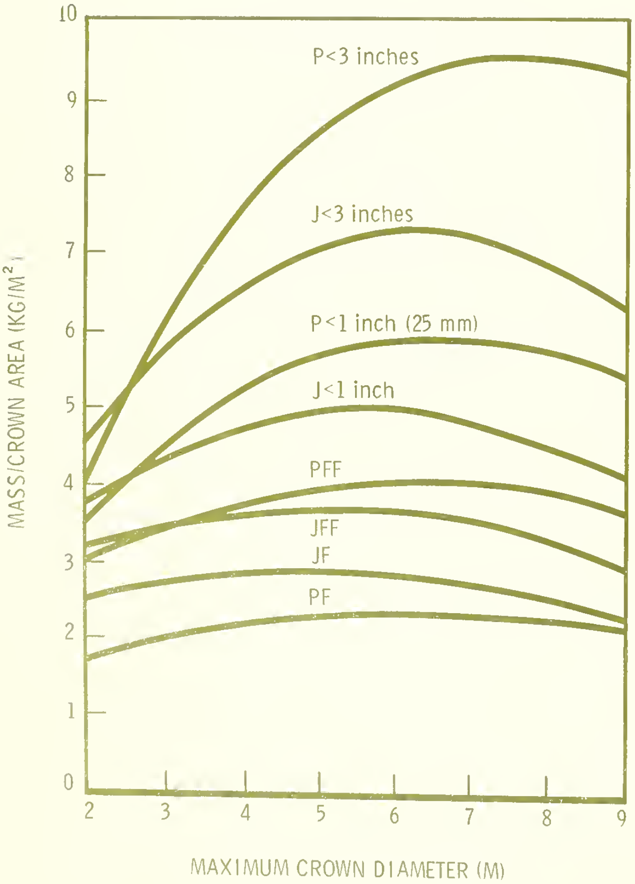

Figure 1.--Mass of foliage (F), foliage and twigs <1/4 inch or fine fuels (FF), all fuels smaller than 1 inch (25 mm) diameter, and all fuels smaller than 3 inches (76 mm) diameter per square meter crown area of singleleaf pinyon and Utah juniper at maximum crown diameters from 2 to 9 meters (from table 3).

As we go to larger size classes, the effect of crown size becomes greater and the maxima occur at larger crown diameters. Mass per unit crown area of stems and branches larger than 3 inches in diameter increases at a constant rate (pinyon) or a slightly increasing rate (juniper) as crown diameter increases (fig. 2).

Litter and duff mass per unit crown area is nearly proportional to crown diameter. Pinyon litter tends to be deeper than juniper litter for a given crown size, but juniper litter tends to be more tightly packed; so the net result is virtually no difference in litter mass per unit crown area between the two species. Although pinyon and juniper produce less litter annually than most other tree species, decomposition rates are low and accumulated litter is a major fuel component.

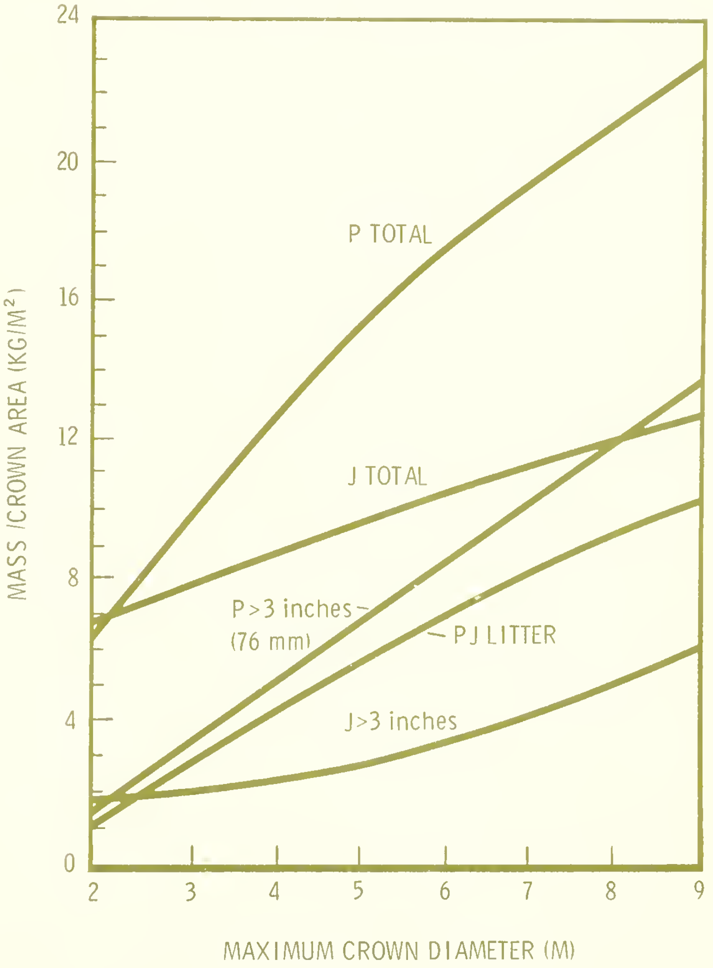

Figure 2.--Total aboveground biomass, mass of stem and branchwood larger than 3 inches (76 mm) diameter and mass of litter and duff per square meter crown area of singleleaf pinyon and Utah juniper at maximum crown diameters from 2 to 9 meters (from table 3). Because pinyon and juniper litter curves are nearly identical, the curve for pinyon and juniper combined is shown.

The amounts of deadwood and moisture in each fuel component are very important in evaluating flammability. Estimates of these are provided in table 2. In all size classes except twigs smaller than 1/4 inch, juniper had a much lower percentage of deadwood than pinyon. Deadwood percent in juniper generally increases with increasing crown size. In pinyon, percent of deadwood larger than 1 inch tends to increase as crown size increases, but percent deadwood smaller than 1 inch is about the same for all crown sizes.

The mean moisture contents of the components (table 2) were calculated from moisture contents at the time the trees were cut. No trends in moisture content throughout the summer were detected, but foliage and twigs probably contain more moisture during the peak growing season in the spring.

Table 2.--*Mean percent deadwood and mean percent moisture (dry weight basis) in the fuel components. Means were weighted by reciprocal of crown area. Mean moisture content of deadwood of both species was 14 percent.*

			Moisture content			
	Deadwood		Live only		Alive and dead	
Component	P[1]	J[1]	P	J	P	J
	Percent					
Foliage	--	--	104	91	104	91
Twigs <1/4 inch	25	25	108	91	85	72
Fine fuels	11	5	106	91	96	87
1/4 - 1 inch	27	16	96	100	74	86
≤1 inch[2]	16	8	103	93	89	87
1 - 3 inches	21	5	79	96	66	92
<3 inches	17	7	95	94	81	88
≥3 inches	4	1	79	92	76	91
Total	11	5	87	93	79	89

[1] P = pinyon; J = juniper.
[2] One inch = 25 mm.

ESTIMATION TECHNIQUES

The regression equations and means in table 1 can be used in several different ways to estimate fuel loading and biomass from aerial photographs, depending on what information is desired and on available photo coverage.

If an approximation of average fine fuel loading is needed for a large area, it can be obtained by determining the proportion of canopy cover on the area of interest and multiplying it by the mean for both species (3.64 kg/m^2, table 1). This simple procedure is adequate because fine fuels per unit crown area are about the same for both species at all crown sizes. This procedure might be used also for the 1/4- to 1-inch size class but, for any other component, more elaborate techniques are required.

If an estimate of litter is desired, a sampling procedure for determining crown diameter is needed because of the dependence of litter mass per unit crown area on crown size.

For estimates of size fractions larger than 1 inch, it is necessary to identify species on the photographs or know, from other sources, the relative proportions of pinyon and juniper on the site and their relative size distributions. A photo scale of 1:5000 or larger is needed to distinguish between pinyon and juniper. (Personal communication, Paul Tueller, Professor, Division of Renewable Natural Resources, University of Nevada Reno.)

The following procedure is suggested for sampling on photographs of sufficient resolution to allow reasonably accurate determination of species and crown diameter. The sampling unit is a 10-point grid, with an equivalent spacing of 10 to 20 meters between points, placed on the photograph. For each point on a crown, measure maximum crown diameter to the nearest meter and determine species. For each fuel component of interest, read from table 3 the mass per unit crown area (kg/m^2) at each occupied point. The sum of these values divided by 10 (the number of points in the sampling unit) is the estimated fuel component mass in kilograms per square meter of land area. Since 1 kilogram per square meter equals 10 metric tons per hectare, the sum of the values is estimated fuel loading in metric tons per hectare.

For example, say three pinyons with maximum crown diameters of 3, 4, and 8 meters and two junipers with maximum crown diameters of 2 and 4 meters are tallied on a 10-point sampling unit. The estimate of fine fuels for that sampling unit is 18.0 MT/ha (3.5 + 3.8 + 4.0 + 3.1 + 3.6). The estimate of stems and branches larger than 3 inches in diameter is 24.0 MT/ha (3.3 + 4.9 + 11.7 + 1.7 + 2.4). Estimated litter is 21.5 MT/ha or, if we use the line for pinyon and juniper combined, 21.1 MT/ha.

A survey would consist of many such sampling units. Stratification based on tree density, landform, soil taxa, and other such criteria would probably increase precision.

This procedure can be easily modified to meet particular needs. In addition to providing fuel loading information for fire management, the technique may be used for other purposes, such as obtaining rough estimates of cordwood volumes and the amount of slash that would result from cutting operations.

Table 3.--*Mass of fuel components per unit crown area of singleleaf pinyon and Utah juniper, based on the regression equations in table 1*

Component	Species	Maximum crown diameter (meters)									
		1	2	3	4	5	6	7	8	9	10
		Kg/m²									
Foliage	P	1.5	1.8	2.0	2.2	2.3	2.3	2.3	2.3	2.2	2.0
	J	2.2	2.5	2.7	2.9	2.9	2.9	2.8	2.6	2.3	1.9
	P&J	1.8	2.1	2.3	2.4	2.5	2.5	2.5	2.4	2.2	2.0
Twigs <1/4 inch	P	0.5	1.1	1.5	1.6	1.7	1.7	1.7	1.6	1.5	1.4
	J	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Fine fuels	P	2.5	3.0	3.5	3.8	4.0	4.1	4.1	4.0	3.7	3.4
	J	2.7	3.1	3.5	3.6	3.7	3.7	3.5	3.3	2.9	2.4
	P&J	2.6	3.1	3.5	3.7	3.9	3.9	3.9	3.8	3.6	3.2
1/4 - 1 inch	P	--	0.6	1.2	1.5	1.7	1.8	1.9	1.8	1.8	1.6
	J	0.4	0.7	0.9	1.1	1.3	1.4	1.4	1.4	1.3	1.1
<1 inch[1]	P	2.1	3.6	4.6	5.3	5.7	5.9	5.9	5.8	5.5	5.0
	J	3.1	3.8	4.4	4.8	5.0	5.0	4.9	4.6	4.2	3.5
1 - 3 inches	P	--	0.6	1.5	2.3	3.0	3.5	3.8	4.0	4.1	3.9
	J	--	0.6	1.4	1.9	2.2	2.3	2.4	2.3	2.3	2.1
<3 inches	P	0.9	4.0	6.1	7.7	8.7	9.4	9.7	9.7	9.5	8.9
	J	3.2	4.6	5.8	6.6	7.1	7.4	7.3	7.0	6.4	5.6
>3 inches	P	--	1.6	3.3	4.9	6.6	8.3	10.0	11.7	13.3	15.0
	J	1.6	1.7	2.0	2.4	2.8	3.4	4.1	4.9	5.7	6.7
Total	P	2.0	6.4	9.7	12.5	14.9	17.2	19.2	21.1	22.9	24.6
	J	5.1	6.6	7.8	8.8	9.7	10.5	11.3	12.0	12.6	13.2
Litter	P	--	0.8	2.6	4.2	5.6	6.9	8.0	8.9	9.6	10.2
	J	0.3	1.6	2.9	4.2	5.5	6.8	8.1	9.5	10.8	12.1
	P&J	--	1.0	2.7	4.2	5.6	6.9	8.0	9.0	9.8	10.4

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[1] One inch = 25 mm.

For cordwood and slash, we would tally only those trees large enough to harvest. The average ratio of stump diameter to crown diameter for pinyon and juniper is 1 to 14. If we assume a minimum stump diameter of 15 cm (6 inches), the minimum crown diameter is 210 cm and we would tally only those trees with crown diameters greater than 2 meters. Continuing with the example given above and taking the larger than 3-inch size class as cordwood, the estimate of cordwood for the sampling unit is 19.9 MT/ha pinyon and 2.4 MT/ha juniper. The smaller juniper did not count. These figures can be converted to cubic foot volume or cords per acre with the following conversion factors:

Pinyon: 1 MT/ha = 31 ft^3/acre = 0.36 cords/acre
Juniper: 1 MT/ha = 38 ft^3/acre = 0.44 cords/acre

The estimated cords per acre on the example sampling unit is 7.2 pinyon and 1.1 juniper.

For the slash estimate, we use the smaller than 3-inch component and obtain 30.1 MT/ha (6.1 + 7.7 + 9.7 + 6.6) for the three pinyons and one juniper tallied on the sampling unit. Since 1 MT/ha = 0.446 tons per acre, this amounts to about 13 tons of slash per acre from cordwood cuttings.

Other applications can be developed for this technique, but it should be remembered that the results are approximate. The CVR% values in table 1 show that estimation errors can be quite high, particularly for the larger size classes. Some form of double sampling, incorporating on-the-ground measurements of stem diameter and height, would be needed to improve estimates of the larger size classes.

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Research Note

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SHOOT DEVELOPMENT IN YOUNG ASPEN

George A. Schier[1]

ABSTRACT

The effect of branching on second-year terminal growth of rooted sucker cuttings was studied in fourteen aspen clones. Cuttings with lateral shoots made significantly less growth than cuttings without lateral shoots. In cuttings having lateral shoots there was a negative correlation between second year growth and numbers of lateral shoots.

KEYWORDS: *Populus tremuloides*, trembling aspen, shoot growth, branching, rooted cuttings, clonal variation.

In a recent study of vegetative regeneration of aspen (*Populus tremuloides* Michx.) ollowing burning and clearcutting, it was found that the amount of height growth of oot suckers was much less during the second growing season than during the first (Schier nd Campbell 1978). This may have been due to the depletion of reserves in the parent oots. The reduction in height growth during the second year, however, may have also een due to the outgrowth of lateral buds (inhibited the first year[2]) and the consequent ompetition between terminal and lateral shoots for the limited supply of water, minerals, nd photosynthates.

The effect of branching on terminal growth of aspen can be studied by comparing econd year growth of rooted sucker cuttings with and without lateral buds. Cuttings ithout lateral buds are common in some clones because shoots set terminal buds and ecome dormant during rooting, prior to the initiation of lateral buds. The axils of rimary leaves on these cuttings do not have buds. Cold treatment is necessary efore shoot elongation will continue. Cuttings that do not go dormant during rooting ontinue terminal growth and develop a shoot with lateral buds, which elongate during he second year. In clones with high variability in the numbers of lateral shoots, ffect of branching on terminal growth may also be shown by a regression of terminal rowth on numbers of lateral shoots.

Terminal shoot growth in aspen involves the elongation of preformed stem units in he winter bud (i.e., fixed growth) followed by a period of free growth during which the nitiation and elongation of new stem units occur simultaneously.

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[1] Plant Physiologist located at the Forestry Sciences Laboratory, Logan, Utah.

[2] It is normal in aspen for the lateral buds on the current year's growth to be ompletely inhibited.

METHODS

Roots for vegetatively propagating aspen were collected in May 1976, from 20 aspen clones growing in Logan Canyon east of Logan, Utah. Suckers were grown from root segments and sucker cuttings rooted by the methods described by Schier (1978). During the last week in July, 30 cuttings having the best root systems were selected from each clone and planted in 6.4 by 25.4 cm tubes with a vermiculite:peat moss (1:1) potting mi The containerized aspen were randomly placed on a greenhouse bench where they were ferti lized with a complete granular fertilizer and watered periodically. To increase the amount of growth made by the ramets during their first year, day lengths were extended with artificial lighting from August 1 to October 26. Most ramets continued to grow during the long days; however, a significant number set terminal buds during rooting an went dormant. On October 26 the ramets were moved to a "cold" compartment 34° to 46°F (1° to 8°C) in the greenhouse.

During the second week in April 1977--prior to flushing--the ramets were transplanted into 1-gallon pots with a peat moss:sand (4:3) potting mix and fertilized. They were moved outside to a lath house (50 percent shade) where the clones were randoml arranged on benches, and the plants were watered as needed to keep the soil moist. In October, after leaf fall, terminal shoot growth increments were measured and numbers of lateral shoots counted.

Bud set during rooting of cuttings occurred with greater frequency in some clones than others. Those clones in which bud set was common were used for comparing terminal growth increments of ramets with and without lateral shoots. Clones in which many of the ramets made good first-year growth were used for determining the relationship between second-year terminal growth and number of lateral shoots.

RESULTS

Second-year terminal growth increments of ramets with lateral shoots were significantly less than those without lateral shoots (table 1). The reduction in growth of terminal shoots caused by the presence of laterals ranged from 33 percent in clone 2 to 66 percent in clone 4. The second-year height increment made by ramets without lateral shoots enabled them to make up for their poor growth the first year caused by early bud set. Therefore, by the end of the second year, none of the clones showed a significant difference in total height between the two classes of ramets.

Table 1.--*Second year terminal growth of aspen ramets with (a) and without (b) lateral shoots on the first year's stem growth*

Clone	Mean and range in numbers of lateral shoots	Mean terminal growth: First year	Mean terminal growth: Second year
		- - - - - *Centimeters*	- - - - -
1	a. 6.4 ± 1.9 (3-10)	52.3 ± 9.7	46.7 ± 10.8 **
	b. 0	2.4 ± 0.9	94.9 ± 24.0
2	a. 3.8 ± 2.8 (1-10)	28.7 ± 12.3	62.5 ± 26.6 **
	b. 0	3.3 ± 1.1	104.8 ± 16.7
3	a. 2.3 ± 2.2 (0-6)	38.3 ± 10.8	64.6 ± 29.2 *
	b. 0	5.3 ± 4.4	83.6 ± 16.0
4	a. 7.6 ± 2.4 (4-13)	57.2 ± 10.2	51.1 ± 16.0 **
	b. 0	2.4 ± 1.2	115.4 ± 15.7
5	a. 4.8 ± 1.8 (1-7)	41.7 ± 9.6	58.1 ± 9.3 **
	b. 0	3.1 ± 1.7	88.3 ± 17.2

*/** Differences between ramets with and without lateral shoots that were significant at 5 and 1 percent levels, respectively.

To determine if top growth of larger plants had been reduced by restricted root growth, the root systems of a small sample of plants in each clone were examined. There was no evidence that root spiraling had become severe enough to reduce root vigor.

The relationship between terminal growth and number of lateral shoots was examined in nine clones (table 2). There was a significant positive correlation between the number of branches borne by the portion of the stem elongating the first year and the first-year height increment. This would be expected because the number of nodes on the stem, where leaves and lateral buds occur, is determined by the amount of stem growth. (Within a clone, mean internode length during height increment of a given year did not show much variation. Less than 20 percent of the variation in terminal growth was due to an increase in internode length.) The primary cause for the variation in correlation coefficients among clones was the variation in numbers of lateral buds breaking dormancy. Clonal differences in numbers of lateral branches were highly significant (1 percent level).

Table 2.--*Terminal growth and number of lateral shoots on 2-year-old aspen ramets and relationship between stem growth and branch number (correlation coefficient). Lateral shoots occurred on the part of the stem elongating the first year*

	Mean terminal growth		Mean and range in numbers of lateral shoots	Correlation coefficients (r)		
Clone	First year	Second year		Branch No.[1] / First year growth	df	Second year growth / Branch No.
	- - - *Centimeters* - - -					
6	36.8 ± 8.6	44.6 ± 18.8	5.5 ± 3.5 (0-12)	0.24	18	-0.88**
7	47.9 ± 11.4	40.1 ± 14.1	10.4 ± 4.3 (2-16)	.86**	25	-.71**
8	31.0 ± 13.1	84.3 ± 28.8	6.2 ± 3.1 (2-12)	.79**	17	-.64**
9	43.0 ± 8.8	62.1 ± 23.6	5.4 ± 2.7 (0-11)	.62**	18	-.50*
10	46.9 ± 11.0	66.0 ± 20.0	7.1 ± 3.6 (3-15)	.48*	21	-.54**
11	33.8 ± 9.0	46.4 ± 17.1	4.6 ± 3.3 (0-13)	.51**	24	-.75**
12	52.3 ± 9.7	46.7 ± 10.8	6.4 ± 1.9 (3-10)	.54*	16	-.34
13	42.0 ± 9.2	82.4 ± 16.6	3.5 ± 2.0 (1-6)	.67**	12	-.44
14	57.2 ± 10.2	51.0 ± 16.0	7.6 ± 2.4 (4-13)	.58*	12	-.59*

*/** Significant at the 5 and 1 percent levels, respectively.

[1] dependent variable / independent variable

Second year terminal growth showed a significant negative correlation with the number of lateral shoots in seven of the nine clones (table 2). Because the number of branches was determined by the first-year height increment, second-year terminal growth was also negatively correlated with first-year shoot growth. In other words, the greater the ramets grew the first year the less they grew during the second. This compensating mechanism tends to reduce the variation in total height of ramets within a clone during early growth.

Second-year terminal growth was also negatively correlated with the total length c lateral shoots, but the relationship was not as clear as that between shoot growth and branch number.

DISCUSSION

The results presented in this study indicate that annual height increment of aspen root suckers decreases during their second year because of the outgrowth of lateral buds. This is not surprising because the various growth processes that proceed simultaneously in a plant are not independent, but closely linked with one another. To some extent these growth correlations--as they are often called--can be attributed to the availability of nutrients, or food factors, and the competition between growing regions for these substances. Reduced terminal growth of aspen ramets during crown development may also be the consequence of internal water deficits (Borchert 1975). Branching increases the total leaf area and therefore causes a greater loss of water by transpiration.

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COMPARISON OF PERCENT SHRINKAGE AND SPECIFIC GRAVITY FOR THREE TYPES OF WESTERN WHITE PINE WOOD

Glenn L. Gernert, Arland Hofstrand, and David P. Lowery[1]

ABSTRACT

Live, dead down, and dead standing western white pine trees were sampled in north Idaho for the purpose of comparing the physical properties of live and dead trees. Twelve areas were sampled with three trees of each type per area. Volumetric, tangential, and radial shrinkage and specific gravity were the properties measured. No significant difference at the 5 percent level was observed among means of each physical property in the tree types sampled. Some sample areas, however, differed significantly. Mean moisture contents were also calculated for each tree type. The means for live, dead down, and dead standing trees were 73.32, 42.02, and 33.21 percent, respectively.

KEYWORDS: western white pine; dead trees; specific gravity; percent shrinkage.

Western white pine (*Pinus monticola* Dougl.) is one of the most important and valuable timber species of the Northern Rocky Mountains. During the past few years, the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) and the blister rust (*Cronartium ribicola* J.C. Fisch.) have killed a large number of white pine trees in this area. Efforts to salvage and utilize the dead trees have been only partially successful and the volume of dead white pine timber on the Region's National Forests is increasing.

One of the principal uses of white pine lumber has been as door and window frames and sash. For this purpose, dimensional stability is critical. Although the wood from dead trees remains sound and usable for many years after death, lack of information on the specific gravity and shrinkage characteristics of the dead tree wood has deterred its substitution for the green tree lumber normally used by the millwork industry.

The objective of this research was to determine the moisture content, specific gravity, and the radial, tangential, and volumetric shrinkage of specimens cut from dead down and dead standing white pine trees and to compare these values with values obtained from specimens prepared from live trees.

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PROCEDURE

Sampling

Sample material was obtained from 12 harvesting areas scattered throughout the species range. The areas were subjectively selected to provide the largest geographical distribution possible. On each area, three trees of each type--live, dead down, and dead standing--were selected for sampling. The selected trees were free of major decay and had a minimum diameter of 10 inches (25.4 cm) at a height of 32 feet (9.75 m). The diameter requirement insured that sufficient material would be available for test specimens.

The selected trees were felled if necessary, and an 8-inch (20.3 cm) sample section was cut from above the first log (approximately 32 feet [9.75 m]). Sampling at this point minimized the loss of wood. Also, the sample section was probably more representative of the tree than samples taken at the base or the top of the merchantable bole.

Sample sections were immediately labeled, end coated to prevent moisture loss, and placed in plastic bags. The samples were stored in an unheated building until required for the preparation of test specimens.

Preparation of Specimens

Initial breakdown of the sample sections was done on a band saw. Prior to sawing, the 8-inch (20.3 cm) sections were carefully examined to determine the best cutting planes. A cruciform-type cutting pattern was used (fig. 1). The sections were first sawn in two pieces parallel to the grain by removing a 1-inch (2.5 cm) strip containing the pith. Blocks were then cut parallel to the grain from each piece. The blocks were placed in plastic bags and refrigerated until final breakdown, which was done on a table saw.

Test specimens were cut from each block following the procedures outlined in "Standard Methods of Testing Small Clear Specimens of Timber," ASTM D-143-52 (American Society for Testing and Materials 1977). Occasionally, specimens had to be cut from the block slabs because of unexpected knots, decay, or checks encountered in the blocks. Two sets of test specimens, one from each block, were prepared from each tree section. The percent volumetric shrinkage and specific gravity test specimen was 2 by 2 by 6 inches (5.1 by 5.1 by 15.2 cm) and radial and tangential shrinkage specimens were 1 by 4 by 1 inches (2.5 by 10.2 by 2.5 cm) (fig. 1). The initial moisture content of each block was determined using a defect-free piece of the wood and the ovendry test method.

The test specimens were essentially all heartwood. A total of 648 test specimens, 12 areas, 9 trees per area, and 6 specimens per tree were prepared and used.

Testing

The test specimens were first air dried under ambient laboratory conditions. The specimens were weighed and measured at regular intervals during the drying process and individual records were maintained of the dimensional and moisture content changes. Again, procedures outlined in ASTM D143-52 were followed.

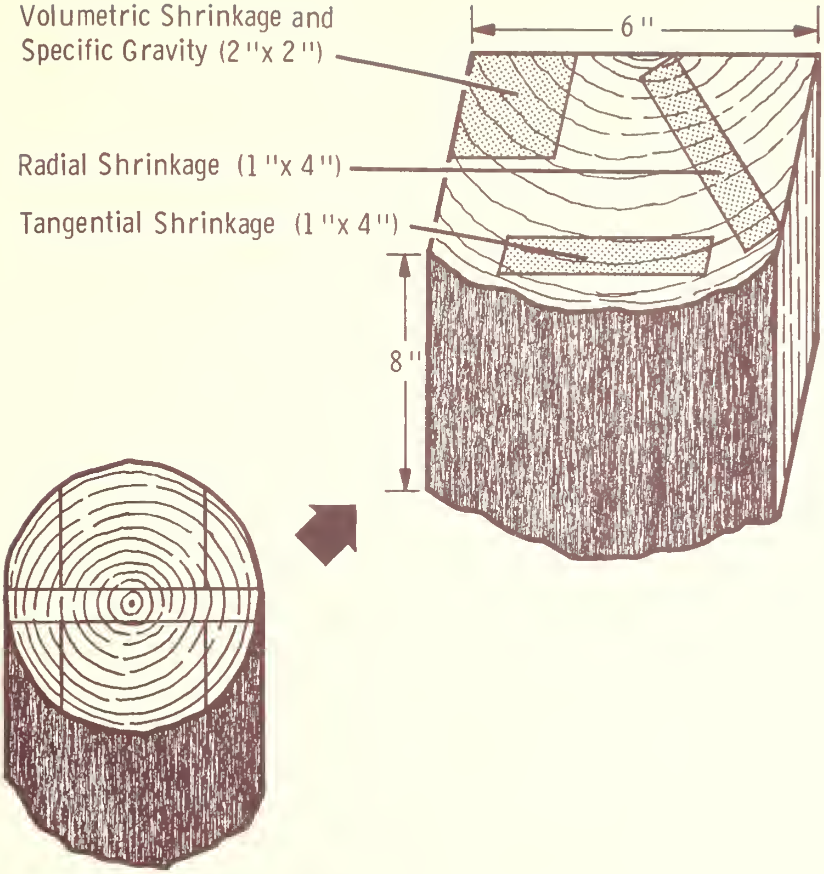

Figure 1.--Drawing showing the cutting pattern used with the log sections and the sampling pattern of the test blocks.

The specific gravity-volumetric shrinkage specimens were end coated with paraffin efore air drying to reduce the drying rate. The specimens were weighed before and fter coating with paraffin so that the weight of paraffin could be deducted in deter-ining moisture content. The paraffin volume was not considered in determining the vendry volume for the specific gravity determination.

After the test specimens reached equilibrium moisture content in the laboratory, hey were ovendried for 24 hours at 212°F (100° C). Final measurements were taken on ach specimen after ovendrying. The volumetric shrinkage-specific gravity specimens ere recoated with paraffin after the final measurements to prevent absorption of water uring volume determination by the immersion method.

Analysis of Data

Shrinkage of wood does not occur until the moisture content is below the fiber saturation point (FSP), which has been defined as that moisture content when the cell walls are saturated and the cell cavities are free from water. Below the FSP the percent shrinkage is essentially linear. Since the FSP is not the same for all species trees, or specimens, it was necessary to calculate the FSP from the data obtained for each specimen.

A linear regression, computed for each test specimen using a maximum of 25 percent moisture content, was used to calculate the total percent shrinkage and the FSP. Percent moisture content was the independent variable (X axis) and percent shrinkage the dependent variable (Y axis). The intercept values of the X and Y axes were used for FSP and the total percent shrinkage, respectively.

The values obtained for each tree of a specific type--live, dead down, or dead standing--were averaged and compared using covariance analysis, which adjusted for differences in specific gravity and moisture content. The percent shrinkage values, volumetric, radial, and tangential, were compared using this same method. Duncan's multiple range test of the means was used to determine which means differed significantl

RESULTS AND DISCUSSION

The analyses of covariance showed no significant differences at the 5 percent level among green, dead down, and dead standing trees' shrinkage characteristics and specific gravities. The results of the analyses for each variable are discussed separately.

Volumetric Shrinkage

By area, the volumetric shrinkage means, adjusted for percent moisture content and specific gravity, ranged from 8.81 to 11.79 percent.

The percent volumetric shrinkage from green to ovendry for western white pine is 11.8 (USDA 1974). The experimental value for all tree types and areas combined is 10.22 percent, fairly close to the published value.

There were no significant differences among the means of the tree type, but there were significant differences among the means of the 12 areas.

Tangential Shrinkage

The tangential shrinkage means adjusted for moisture content and specific gravity by tree type ranged from 6.68 to 8.23 percent and by area ranged from 6.97 to 7.85 percent. There were no significant differences between the means for tree conditions or for the area means.

Tangential shrinkage from green to ovendry is 7.4 percent (USDA 1974). The experimental value was 7.5 percent.

Radial Shrinkage

The covariance analysis of the radial shrinkage showed no significant differences among the sample areas. The overall radial percent shrinkage means adjusted for moisture content and specific gravity by tree conditions were: live 3.49; dead down 3.55; and dead standing 3.37. The mean radial shrinkage by area ranged from 3.07 to 3.83 percent.

The percent radial shrinkage from green to ovendry for western white pine is 4.1 percent (USDA 1974) and the overall study value was 4.5 percent.

Specific Gravity

All specific gravity determinations were based on green volume and ovendry weight.

There were highly significant differences in the mean specific gravity by sample area, but no significant difference among the tree types. The specific gravity area means ranged from 0.321 to 0.366 and the specific gravity tree type means were live 0.346, dead down 0.343, and dead standing 0.332. The overall mean specific gravity was 0.340 and the published value for the species is 0.35 (USDA 1974).

Moisture Content

The overall mean moisture content for live trees was 73.32 and the area means ranged from 59.23 to 96.22 percent. The dead down trees had a mean moisture content of 42.02 and a range of from 26.85 to 73.12 percent. The overall mean percent moisture content for the dead standing trees was 33.21 percent and the range was from 15.38 to 57.21 percent. The sequence of the moisture content means for the three tree types (conditions) was not surprising. Drying had reduced the percent moisture content of the dead trees to approximately half the moisture content of the live trees. The dead down trees had either absorbed moisture from the soil or were more protected by the underbrush than the dead standing trees and so were at a slightly higher moisture content level.

SUMMARY

No significant differences were found among the shrinkage characteristics and specific gravity for live, dead down, and dead standing western white pine trees. Specific gravity and volumetric shrinkage means showed highly significant differences among the 12 sample areas; there were significant differences among the radial shrinkage means by area; and the tangential shrinkage means showed no significant differences among the sample areas.

A reasonably consistent pattern of shrinkage properties is apparent among areas, if one shrinkage value is low, other values tend to be low and if one shrinkage value is high, other values tend to be high (fig. 2). This relationship was not statistically evaluated, but could be attributed to area differences.

The differences between areas can be attributed to a number of factors including elevation, aspect, soil type, genetics, microclimatic, growth conditions, and stand conditions. None of these variables were measured during the sample collection period.

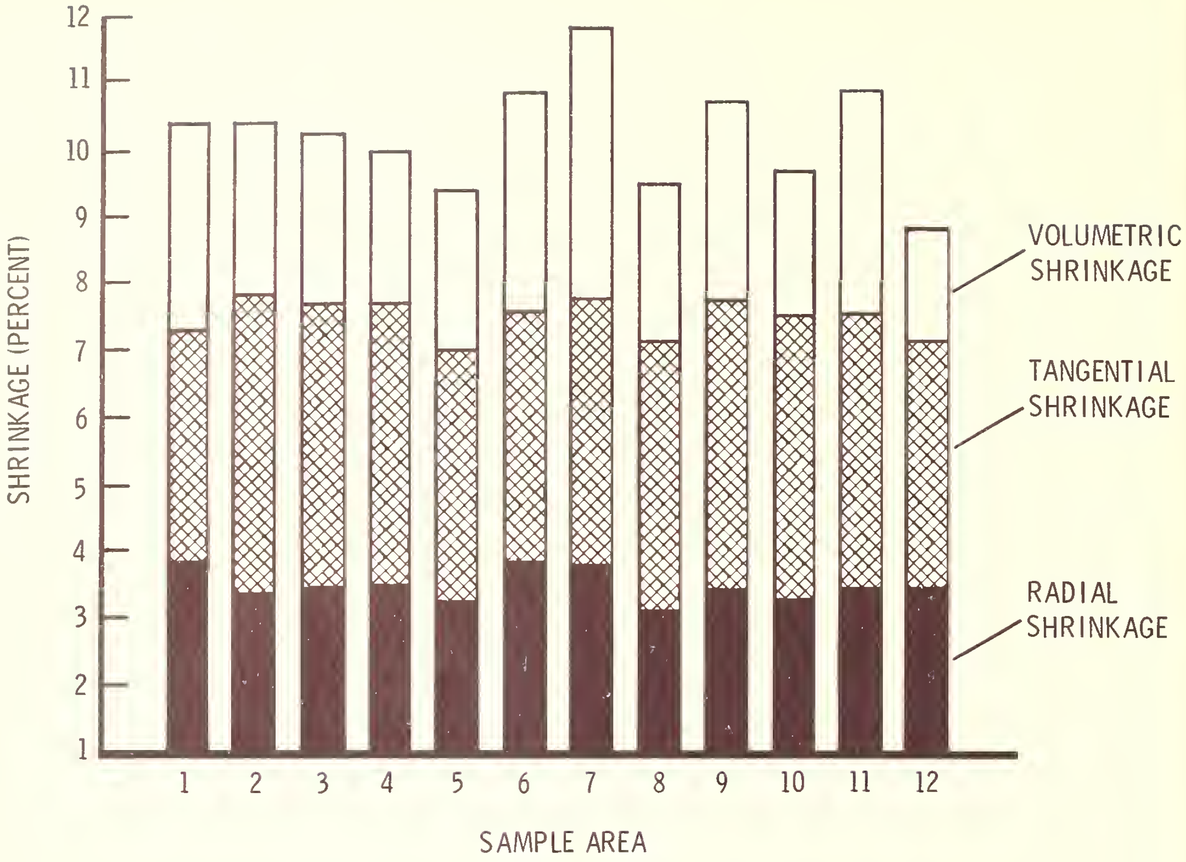

Figure 2.--The adjusted average percent volumetric, tangential, and radial shrinkage by area.

CONCLUSIONS

The results of this study indicate that the dimensional stability of lumber produce from dead western white pine trees is essentially the same as lumber produced from green or live trees. There were no statistically significant differences in the volumetric, tangential, or radial shrinkage values for the live, dead down, and dead standing trees. The mean shrinkage values observed were essentially the same as the publishe values for the species.

There were significant differences among mean shrinkage values for the areas sampled. The sample trees were selected on areas being harvested that were distributed throughout the range of the species and represent a wide variety of growth and stand conditions. Although no detailed field data were obtained from the 12 areas sampled, the significant differences among areas can probably be attributed to the site and growth conditions of the sample trees.

Specific gravity varied significantly among the areas sampled. These differences, too, were probably due to the location and growth conditions of the sample trees.

As would be expected, the live trees had the greatest average moisture content, 3.3 percent, and the dead standing trees the lowest, 33.2 percent. The average moisture ontent of the dead down trees was 42.0 percent. The lower moisture content of the ead trees indicates a shorter drying time would be needed in processing lumber from ead trees.

This study indicates that western white pine lumber made from dead trees is not ifferent in shrinkage values or specific gravity from green tree lumber and should be uitable for manufacture into the same products.

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Research Note

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

January 1980

DETERMINING THE MOISTURE CONTENT OF SOME DEAD FOREST FUELS USING A MICROWAVE OVEN

Rodney A. Norum and William C. Fischer[1]

ABSTRACT

This note describes tests conducted to evaluate performance of a standard kitchen-type microwave oven for determining moisture content of dead woody fuels. Procedures are suggested for using the microwave oven to obtain fuel moisture information. Examples are also provided of field use.

KEYWORDS: Forest fuels, fuel moisture, prescribed fire

In order to employ the newest guidelines for prescribed forest burning and to use nodern fire behavior models, fire managers must know, with good accuracy, the moisture ontent of the forest fuels.

At present, the most widely available means of determining the moisture content of uel samples is by gravimetric determination (commonly called ovendrying). Representaive fuel samples are gathered from the site to be burned, placed in airtight containers nd taken to a facility where they can be weighed, dried, and then weighed again after rying. Using a standard drying oven, this process is completed in about 24 hours. This procedure serves the needs of fire research, but presents a dilemma to the operaional prescribed burner. He or she must know the moisture contents before ignition to e assured that conditions are right for achieving the desired fire treatment. A means s needed to learn the moisture content of forest fuels sampled from the planned or xpected fire area, shortly after the samples are gathered.

Standard, commercially available kitchen microwave ovens offer a solution. Palmer nd Pace (1974) have suggested the use of microwave ovens for determining fuel moisture f wildland fuels. Using chamise and manzanita as test fuels they conclude that drying uel in a microwave oven offers an economical, rapid method for measuring fuel moisture ontent. More recently, Hankin and Sawhney (1978) have shown the advantages of using he microwave oven to determine the moisture content of soil samples.

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Tests of this kind of oven were performed at the Northern Forest Fire Laboratory. Dead, woody fuels with a moisture content below 20 percent can be dried in a matter of minutes and even very wet samples (200 percent MC) could be brought to ovendry conditio in a very short time (less than one-half hour).

BACKGROUND

The moisture content of dead forest fuels, especially the duff, has been consistently identified as a critical variable in prescribed burning (Norum 1976; Beaufait, Hardy, and Fischer 1977; VanWagner 1972). Both fire control and the work done by prescribed fires is strongly influenced by fuel moisture contents. Also, duff moisture content is a particularly important factor in determining the impact of prescribed fire on the soil (Shearer 1975). In some cases a small change in fuel moisture content may make a significant difference in the effects of prescribed fires or the behavior of wildfires. In those cases, no estimate of the fuel moisture content should be used except that gained from a sampling of the actual fuels to be burned.

Various means of estimating the moisture content of forest fuels have been tried, and some are commonly used. Traditionally, 1/2-inch ponderosa pine fuel moisture indicator sticks have been used to evaluate moisture content of dead fuels for prescribed burning of logging slash. Some experienced fire mangers have found these analogs of fuel moisture useful in judging the probable fire behavior of planned fires (Morris 1966). The relevance of fuel moisture sticks to the actual moisture content of logging slash has, however, been seriously questioned by Peck (1969). He found that fuel stick moisture content had no predictable value for any of the fuels he examined. Beaufait, Hardy, and Fischer (1975) found a very low correlation coefficient when they compared actual moisture contents to fuel stick moisture content. Some computational procedures employ environmental parameters to calculate various burning indexes. For some purposes these indexes are adequate, but where prescribed burning guidelines or fire behavior models indicate a response that is sensitive to changes in fuel moisture content, they should not be used to make fire decisions. Serious errors in fire treatment or poor prediction of fire behavior can result.

McLeod (1976) recently developed a prototype portable microwave moisture meter that has shown much promise for measuring moisture content of forest fuels. Tests of this instrument are still being conducted, and final determination of its accuracy is still t be accomplished. Consequently, even with the best results, such an instrument will not be generally available for several years. The use of a microwave oven offers an alternative, if proper procedures are followed.

PROCEDURE

The procedure is basically quite simple although certain precautions must be taken. Fuel samples are gathered, usually by size class or type, from points distributed across the area to be burned. Each sample is weighed before drying to get its weight. It is then placed in the microwave oven for a period of time sufficient to drive off all of the contained water, and then it is weighed again to get its dry weight. The moisture content is then calculated from the simple equation:

$$\%\ \text{Moisture content} = \frac{(\text{Wet weight} - \text{Dry weight})}{\text{Dry weight}} \times 100$$

When using a microwave oven, containers made of nonmetallic material must be used. They should also be nonabsorbent because the weight of water in some fuel samples may be quite small, and any water driven from the container itself will enter as an error if the fuels are weighed in the containers. Also, the containers should be fairly flat and wide rather than tall and thin. The top or bottom of a glass petri dish was found to be an ideal container. Even in flat, wide containers, it is advisable to periodically (every 5 minutes) carefully stir wet, compact samples such as moist duff in order to ensure complete drying.

Most microwave ovens are currently designed to work with some "load" in them when they are turned on. This means that some microwave absorbing material should be in the cavity to avoid damage to the oven. Moistened sponges serve very well. During the tests, three or four 3x5x1/2-inch sponges were wetted, gently wrung out, and placed on the floor of the oven against the walls. Care should be taken to be sure they are kept moist but not soaked during the fuel drying process.

TEST STUDY

Fresh duff and dead branchwood of Douglas-fir and western larch was collected from forests near Missoula, Montana. Duff and 0-1/4-inch dead, woody fuels were tested separately. These materials were separated into lots and conditioned for various levels of moisture content. Samples of about 40 grams each were mixed thoroughly and halved. One half was dried in a standard oven for 24 hours, and the other half dried in a microwave oven. The microwave dried samples were removed from the oven at the end of successive three-minute cycles, stirred and weighed until no further weight loss was detected. The wettest duff samples (230 percent) reached the ovendry state after eight cycles, or 24 minutes in the oven. The wettest 0-1/4-inch samples (90 percent) dried completely in six cycles, or 18 minutes of drying.

Ninety-six pairs of 0-1/4-inch samples and 105 pairs of duff samples were processed. Comparing the results shows a simple linear correlation coefficient of 0.99 for the duff samples and 0.99 for the 0-1/4-inch samples, indicating the microwave ovendrying gave the same results as standard ovendrying. The range of duff moisture content samples was 5 percent to 230 percent and the 0-1/4-inch moisture content ranged from 10 percent to 90 percent.

CONCLUSIONS

The procedure described for microwave ovendrying of dead, woody fuels gave the same results as standard ovendrying. The differences are certainly small enough to be expected, and can be attributed to sampling variability. Some additional trial runs were made using different cycles times, but no signficant changes in procedure are suggested. There does seem to be a slight advantage in uniformity of results and rapidity of drying when 5-minute cycles are used. A total drying time of 25 minutes for very wet duff and 20 minutes for very wet twigs should be adequate if the samples are carefully stirred at intervals of 3 to 5 minutes. A dry glass rod or some similar instrument should be used for stirring, and great care must be taken to ensure that no material adheres to the rod or is lost from the container.

FIELD USE

Microwave ovens are being successfully used for drying fuels under field conditions, powered by light portable electric generators. To minimize the risk of damage to the oven when traveling over rough roads, shock mounting with modified aircraft-type shock mounts intended for electronic equipment is advisable. If the oven is transported in the open bed of a pickup, some sort of weatherproof dust cover is needed.

An example of a field-going microwave oven outfit is the one being used by Fire Management Officer George Ogden on the Bonner's Ferry Ranger District of the Kaniksu National Forest in Idaho (fig. 1). George's outfit consists of four pieces; a standard kitchen-type microwave oven, a shock-mounted platform, a portable 3000-watt generator (fire camp type), and a triple beam balance. These items are shown packed for transport in figure 2 (the platform would be in place under the oven during transport and use). The oven and balance are cushioned with foam rubber to avoid damage during transport (fig. 3 and 4).

With a microwave oven and a reasonably accurate scale, the moisture content of fuels sampled from a proposed fire area can be determined on site in less than one-half hour. This, combined with carefully written prescriptions (Fischer 1979), provides the fire manager with the means to make better decisions leading to improved fire treatments. The same technique, using fire behavior models, will lead to better predictions of the behavior of wildfires and offer sound information for suppression strategies.

SAFETY PRACTICES

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

The procedures recommended here are for drying dead, woody fuels only. They do not apply to live, green fuels. An acceptable microwave oven procedure for obtaining accurate live fuel moisture contents has not yet been developed.

Figure 1. Pickup mounted microwave oven and generator ready for use.

Figure 2. Field-going microwave outfit ready for transport. Oven is on the left, generator on the right. Small box contains scale. Shock mounted platform would be in place under oven during transport.

Figure 3. Thick foam rubber cushions the oven during transport.

Figure 4. Triple beam balance is transported in foam rubber-lined case.

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A CONCEPTUAL FRAMEWORK FOR INTEGRATING FIRE CONSIDERATIONS IN WILDLAND PLANNING

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Richard J. Barney[2]

Rita P. Thompson[3]

ABSTRACT

Offers a system for land management planning that enables managers to include and evaluate the effects of wildfire or prescribed burning on resources. Diagrams important considerations and decision-making steps.

KEYWORDS: Fire management, fire management planning, land use, land use planning, land management, land management planning, wildland management.

Wildfire is a force that affects all facets of resource management. It can be devastating to a resource management program or it can be beneficial and enhance productivity. Fire's effects on wildland resources are complex, but fire effects must be identified and evaluated by the manager or landowner when planning for management of the land.

We have previously developed a perspective of where fire fits in the general planning framework (Egging and Barney 1978). Fire is presented as one component to either use or exclude in meeting management objectives. It should be considered in evaluating the consequences of any proposed management action. We will now offer a system for integrating fire into planning.

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A PLANNING PROCESS

Before we can integrate fire considerations into planning, we must have a common understanding of the planning process. The land has a certain potential for producing resources, and society has demands and desires for those resources. Land management planning helps the manager establish management direction that will balance resource potential and demand. Based on current and projected supply and demand, managers decide land allocations, use patterns, and procedures that will balance resource potential/demand.

The planning process begins with the situation assessment phase, which comprises three components. One component, focusing on the land area's physical and biological characteristics, determines the productive potential and suitability of a certain land for a specific use or mixes of uses. Existing information and supplemental inventories where needed are used to described the area's resources. The second component determines the landowner's demands and desire. In the case of Federal or State lands, the landowner is the public, and the appraisal process identifies how various publics feel about the way their lands are managed. Issue identification is a first step in any decision-making process and begins the process of public involvement.

Assessments of the physical/biological and the social/political situations appear in figure 1 as two lines proceeding from the start node, 0.

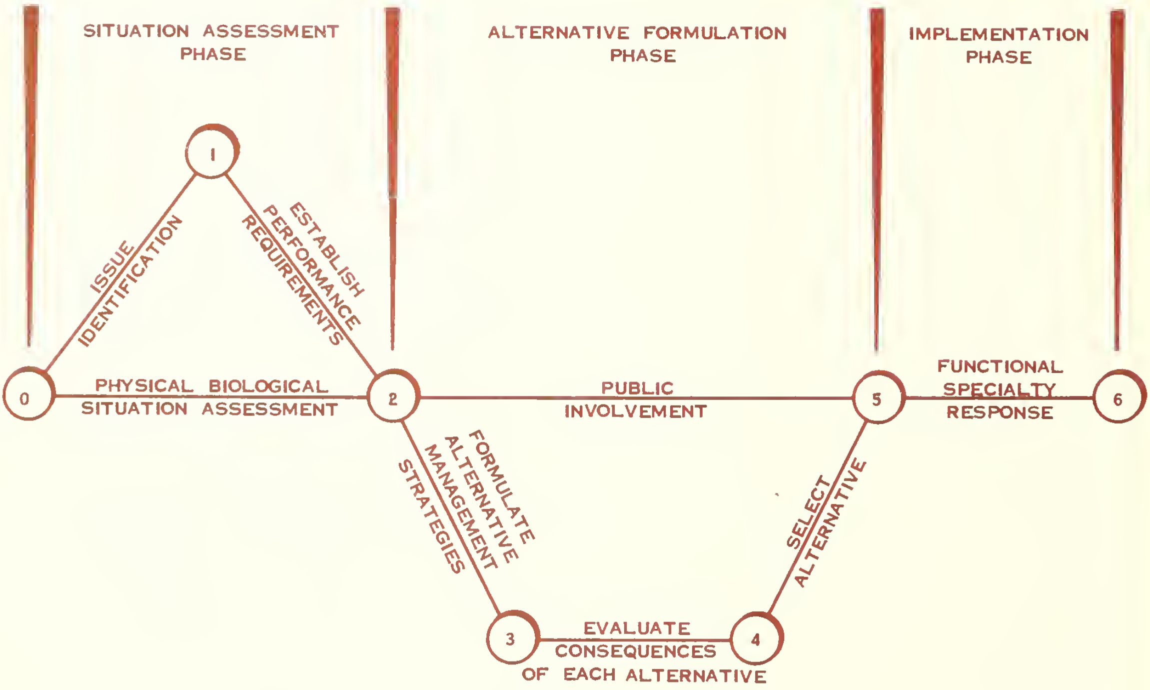

Figure 1.--The general planning process.

In the third component of the situation assessment phase, criteria are established for the planning effort. Criteria are standards, or "rules of the game" that guide trade-offs made throughout the process. They take the form of policy statements; agency goals; needs and demands of local, regional, and national publics; monetary and manpower constraints; and traditional uses.

As portrayed in figure 1, the next phase of planning, beginning at node 2, deals with alternative formulation. A spectrum of management strategies[4] is developed, based on professional judgments about the resource situation and the public's concerns about resource use.

The consequences of employing any management strategy are evaluated in terms of the planning criteria established, and the physical, biological, and economic effects projected over time. Comparing the consequences of alternative management strategies, generally in terms of trade-offs between levels of resource use and values, leads to the selection of the "best" alternative. The public must be kept informed of and involved in the processes used to formulate, evalute, and select any alternative.

After a management alternative is selected, each functional specialty responds by developing a program of work which, when budgeted, becomes the basis for on-the-ground activities that implement the management alternative. This process begins at node 5 in figure 1 and is identified as the implementation phase of the planning process.

FIRE CONSIDERATIONS IN PLANNING

The purpose of including fire considerations in the planning process is to ensure that fire-related decisions are responsive to the management direction established by planning. Depending on the circumstances of its occurrence, fire as a force can both further and preclude the attainment of resource management goals. Therefore, certain types of fire information need to be compiled in the situation assessment phase of planning as part of the physical/biological appraisal process. As a minimum, fire occurrence, fire weather, fire history, and fuels information are gathered. This information is used to stratify areas of fire hazard and potential risk within the planning area.

The fire hazard/risk stratification provides the base information for fire consideration in the alternative formulation phase of planning the process. For each management strategy developed, the hazard/risk stratification and resource management objectives are analyzed and a range of fire management strategies developed. These strategies consider feasible levels of fire control and fire use consistent with the resource potential/demand issue being addressed.

As alternative management strategies are evaluated and compared as to their effects over time, so too are the fire management strategies. The effects of various levels of fire control and use are projected in terms of resource outputs and environmental and economic consequences. An evaluation of effects relative to criteria established earlier in the process facilitates comparing alternatives and the eventual selection of the management alternative to be implemented. Thus, the alternative selected for implementation includes a fire control/fire use strategy to be applied on the area that is responsive to resource management objectives, established criteria, and economic sideboards.

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[4] A management strategy, as used here, refers to a procedure employed to reach a solution to a resource potential/demand problem or issue.

The PERT diagram of planning process, figure 1, is expanded in figure 2 to detail and highlight the fire considerations described above. Nodes 0, 2, 3, 4, and 6 correspond to the same numbered nodes in figure 1.

A FIRE MANAGEMENT DECISION SYSTEM

The overview of a planning process, and basic fire considerations in that process, provide a foundation for developing a responsive fire control/fire use strategy. Fundamental to integrating fire considerations and planning is the ability to project the consequences of a proposed fire strategy on the ecosystem over time. Comparing and evaluating these consequences are key to making the final management decision.

Fire is a force that produces significant effects on the environment. Primary effects on the airshed, soils, and vegetation secondarily affect watershed, wildlife, and the visual quality of an area. Fire can either enhance or degrade site productivit depending on conditions of the burn. It is multifaceted in its effects, both immediate and extended over time. Planners and land managers alike need to consider the full spectrum of fire effects and the effects of alternative fire strategies when making land allocation and resource management decisions.

Because of its complexity as a force and its effects on ecosystems, fire demands a holistic evaluation. The planning system must have the capability to project the effects of fire on all resources over time, to help the manager make specific fire decisions in planning. Such a system is diagrammed in figure 3. Starting with a proposed fire control/fire use strategy to be evaluated, information flows through an estimation of fire behavior, fire effects, and an economic evaluation of consequences. Applying this system to several strategies, the "best" strategy in terms of responsiveness to resource management objectives and planning criteria can be selected for implementation.

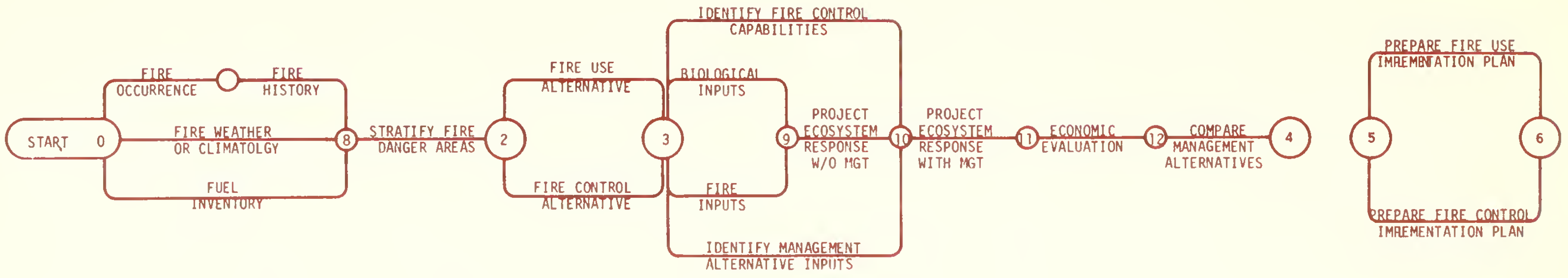

Figure 2.--Fire considerations in planning.

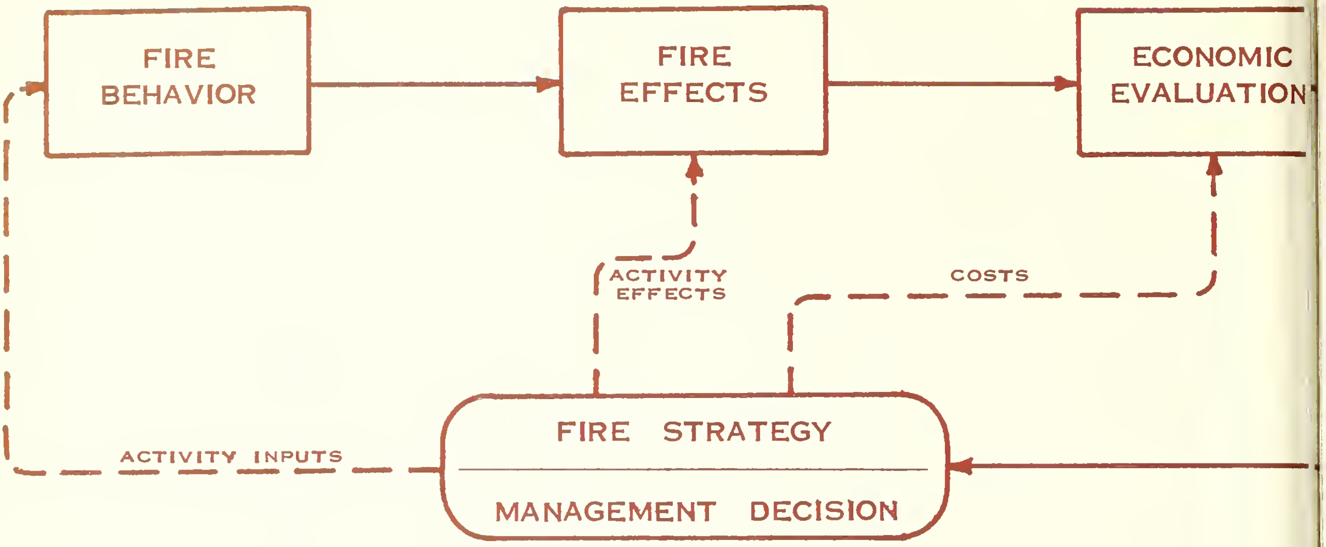

Figure 3.--Information flow for fire management decision system.

The model of a fire management decision system in figure 3 is expanded in figure 4 to show information requirements for the fire behavior, fire effects, and economic evaluation subsystems.

The fire behavior subsystem requires site-specific information on topography, vegetation, weather, and fuels. These data are used to describe the fuels situation in terms of its physical properties (size and distribution) and moisture content. Combining the fuels information with topographic and weather information , models are developed to predict fire behavior (Rothermel 1972; Albini 1976). Fire behavior predictions are in terms of fire intensity, duration, and rates of spread.

Information from the fire behavior subsystem flows to the fire effects subsystem to predict the effects of a fire of certain behavioral characteristics on the resource of an area. The fire effects subsystem has two phases--the prediction of primary effects and the prediction of long-term responses. Immediate or primary effects on soils, vegetation, and air quality are inputs to an ecosystem production module, where these effects are in terms of their long-term consequnces on resource productivity. Primary fire effects information also flows to an environmental response module where interpretations of long-term, off-site effects on water quality, smoke production, and soil erosion are made.

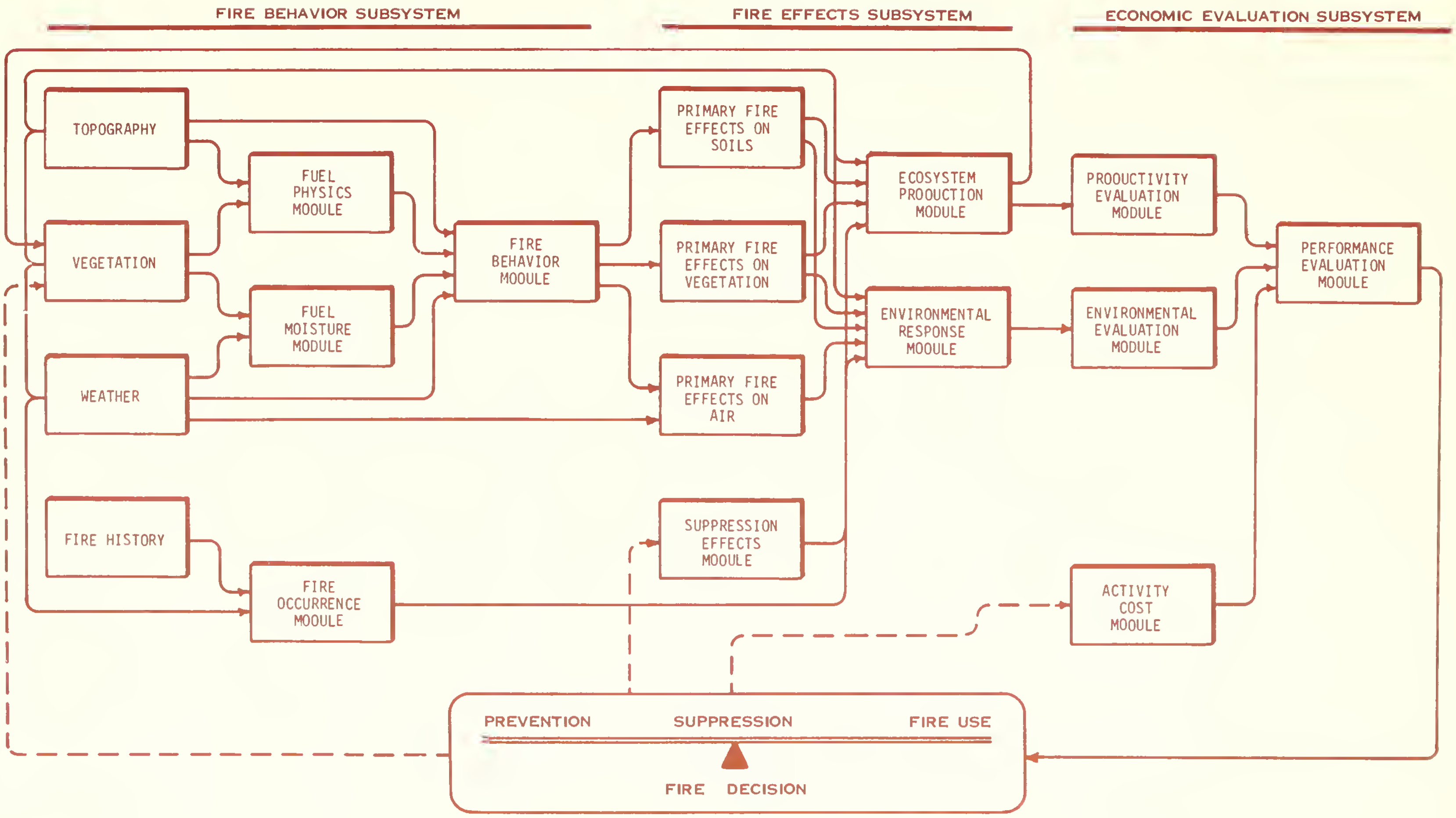

Figure 4.--Fire management decision system.

Long-term fire effects are evaluated from a broad scale economic perspective in the final subsystem of the fire decision system. Changes in resource productivity, derived from interpreting long-term fire effects, are evaluated relative to their social and environmental consequences. These consequences are then tested against the established planning criteria. This evaluation combined with the cost of fire control/ fire use activities required to implement a given fire management strategy provides the basis for comparing strategies.

The ultimate fire decision made in the planning process is the selection of the strategy most responsive to management objectives. The strategy likely will be some combination of fire prevention, fire suppression, and fire use activities.

A general example will help illustrate how to obtain the data needed for the fire management decision system portrayed in figure 4, and how the system might be used in a planning situation.

The starting point for the system is a proposed fire management strategy developed for a given management alternative. One point needs to be emphasized: *There must be a management objective to which the fire management decision made will respond.* Fire management is a support function. As such, it must respond to or be pulled along by management objectives, not drive them. Each management alternative developed in the planning process can have an array of fire management strategies that respond to it. The one or more selected are those fire management alternatives that best meet planning criteria.

USING THE FIRE MANAGEMENT DECISION SYSTEM

Fire Behavior Subsystem

TOPOGRAPHY

Topographic information is obtainable for almost any resource management unit from topographic maps, aerial photographs, satellite imagery, and on-the-ground reconnaissance.

VEGETATION

Some type of vegetation stratification already exists and is mapped for many land areas, and may be entered and digitized in some computer-retrievable format. Vegetation information may be obtained from aerial photographs, satellite imagery, and field reconnaissance.

WEATHER

Most Federal and State agencies have stored weather information in computer form for some period of time. The United States Weather Service also archives weather information for many locations in both daily surface observations and climatic summaries Some of these data are available on written request. Computer compatible tapes or cards can be obtained and used to produce weather information summaries.

FIRE HISTORY

Almost all land management agencies in the country utilize some form of wildfire activity reporting. These data are variously retrievable--some on computer tape, others in office files. In addition, there are several techniques that can be used in the field to determine fire periodicity within a management unit (Arno 1977).

An important point to remember when compiling data to use in information flow models, such as the one described here, is that output from one module becomes input for the next. Input requirements dicate the kind of information to be collected and summarized. The base-type information described above is available at various levels of resolution. The level of planning for which a decision system is being used dictates the resolution. Project level planning requires more precise information than land allocation planning.

The four categories of data mentioned thus far are needed for the fire behavior subsystem of the decision system and provide input for the fuel physics, fuel moisture, and fire occurrence modules. The fuel physics and fuel moisture modules are related to available fire behavior prediction systems. By combining topography, vegetation, weather, the physical characteristics of fuels and fuel moisture yields a fire behavior system closely related to the fire danger rating system (Deeming and others 1978). The fire occurrence module is a tabulation of fire occurrences over time, frequently with a probability of occurrence factor developed.

Fire Effects Subsystem

As seen in figure 4, the outputs generated in the fire behavior module provide initial input to the fire effects subsystem, because a fire's effect on an ecosystem depends primarily on the behavioral characteristics of that fire.

PRIMARY EFFECTS ON SOILS

Factors considered here include: the amount and extent of duff removal; changes in the physical characteristics of the soil, especially its ability to absorb moisture; soil productivity, or the fertility regime as influenced by fire. Effects may be either beneficial or adverse, and will be both short and long term. Figure 4 shows that interpretations of the primary effects of a fire on soils feed into the ecosystem production and environmental response modules.

PRIMARY EFFECTS ON VEGETATION

Effects on vegetation include consideration of: how much vegetation will be burned and in what sort of pattern; which components of the vegetation will be affected--understory, overstory, or both; how much and what types of vegetation will be killed, scorched, or unaffected. All of these effects are functions of fire intensity, duration, rate of spread, and total extent--information generated from the fire behavior module.

AIR QUALITY

The main concern is the amount of particulate that a fire will emit. Output of the fire behavior module helps determine particulate and smoke production.

SUPPRESSION EFFECTS MODULE

A major consideration is determining how effective suppression action can or will be given a fire start in a certain area. Weather, topography, fuel characteristics, vegetation, access, manpower, past activity in the area--all are involved in deriving an estimate of suppression effectiveness.

ECOSYSTEM PRODUCTION MODULE

This "box" is one of two collector modules in the fire effects subsystem. Information gathered and interpretations made on fire behavior and fire effects are used to determine whether the flow of products (commodities and amenities) from an ecosystem will increase, decrease, or be unchanged. The rate and duration of changes in production flow are also determined. Note that outputs of the ecosystem production module feed back to the vegetation module of the fire behavior subsystem. The process diagram in figure 4 is repetitive. Whenever there is a change in any component of an ecosystem, the change is manifest throughout the system. Further, the influence or relationship of that one component on the rest of the system changes also.

ENVIRONMENTAL RESPONSE MODULE

The other collector module, environmental response, represents the place in the decision system where social perceptions of the fire-caused change in the area are documented. Visual quality, water quality, and air quality are examples of the factors considered.

ECONOMIC RESPONSE MODULE

Planning and decision making finally start to happen in this final segment of the fire management decision system. Changes recorded are analyzed and evaluated. The productivity evaluation module assesses changes in resource products--animal unit months of deer, elk, livestock use; board feet of sawtimber; acre feet of water; recreation visitor days--relative to the ecosystem's change over time as a response to fire's influence. Changes in quality perception are likewise evaluated in the environmental evaluation module.

PERFORMANCE EVALUATION MODULE

At this stage, all the predicted and potential changes in an ecosystem stemming from a fire management strategy are weighed against the established planning criteria. If changes meet the criteria, the fire management strategy might be selected for implementation; if not, the strategy could be modified and run through the system again. Note that the activity cost module plugs into that segment of the decision system. All aspects of developing a fire management strategy--hazard reduction, suppression action, prescribed burning, area inventory and reconnaissance--have an associated cost. The cost of a specific activity needs to be evaluated in terms of the changes in and response of the ecosystem relative to management objectives and criteria. As mentioned earlier, management objectives are the driving force in this decision system. The reason for having a fire management decision system is to test a decision's responsiveness to a management objective, both immediately and over time.

SUMMARY

In planning for the management of our wildland resources, fire is one factor that is often overlooked. Fire can significantly affect resource production. It can be either devastating to or supportive of a planned management strategy. Likewise, a management strategy, when implemented, can change the fire situation. To integrate fire and planning, fire considerations must be woven throughout the whole process.

The planning process is viewed as a primary ingredient in the decision-making process. This process is PERT, charted in a general form, then made more specific with fire considerations included.

An important consideration in integrating fire and planning is projecting and evaluating the consequences of fire management strategy in terms of resource response over extended time periods. This segment is diagrammed as the fire management decision system, consisting of three segments--fire behavior, fire effects, and economic evaluation. By utilizing the planning model and fire decision system to help analyze management strategies, the resource planner will be able to make decisions that put fire management strategies into perspective relative to resource management goals. Then fire management will become more responsive to overall resource management.

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Research Note

USDA FOREST SERVICE INT-279
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507-25th STREET, OGDEN, UTAH 84401

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HIGH BROWSE YIELD IN A PLANTED STAND OF BITTERBRUSH

Dean E. Medin and Robert B. Ferguson[1]

ABSTRACT

A 10-year-old stand of antelope bitterbrush [Purshia tridentata (*Pursh*) *DC.*] *established by direct seeding on a deer winter range in southwestern Idaho yielded an exceptionally high 696 kg/ha (621 lb/acre) of ovendry browse in 1967. We suggest that this high year-specific yield, twice that previously reported for bitterbrush, was the result of (1) a favorable circumstance of weather and exceptionally good soil moisture, and (2) soil and site characteristics conducive to bitterbrush growth. The growing season was marked by a cool spring and June rainfall that was twice the long-term average. The soil of the planting site, developed from granitic colluvium, is relatively young, moderately deep, coarse textured, well drained, and slightly acidic.*

KEYWORDS: bitterbrush planting, high yield, weather effects.

Shrubs are increasingly used to restore disturbed rangelands in the Intermountain Region. They offer certain advantages because of their productivity, palatability, nutritional qualities, and value as wildlife habitat and cover for the soil (McKell and others 1972). Yet, relatively little is known about the growth performance of planted shrubs in the Intermountain Region, an area characterized by low rainfall that is poorly distributed spatially, seasonally, and yearly.

During the growing season of 1967 we observed exceptional growth of antelope bitterbrush [*Purshia tridentata* (Pursh) DC.] in southwestern Idaho. Current shoot lengths over 50 cm (20 inches) were common and some exceeded 80 cm (31 inches). To document this growth, we sampled the current yield from a 10-year-old planting of bitterbrush on a deer winter range 32 km (20 miles) east of Boise. The 1.43-ha (3.53-acre) stand was established from seed by the Idaho Fish and Game Department in the autumn of 1957.

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[1] Research wildlife biologist and range scientist, located respectively at Boise, Idaho and the Shrub Sciences Laboratory, Provo, Utah. The authors acknowledge the cooperation of the Idaho Fish and Game Department through Federal Aid Project W-111-R.

The planting is located on a gently rolling terrace of granitic colluvium that i underlain by basalt. Soils are characteristically coarse textured and either gravell or stony. Slope gradients within the planting vary from 6 percent to 15 percent and mostly slope to the southwest. The elevation is 976 m (3,200 feet).

Average annual precipitation is about 50 cm (20 inches), most of which falls as snow in winter. Summer rains generally occur as infrequent, scattered, high-intensit thundershowers.

Common grasses on the site include cheatgrass (*Bromus tectorum* L.), squirreltail (*Sitanion hystrix* Nutt.), bulbous bluegrass (*Poa bulbosa* L.), and bluebunch wheatgras [*Agropyron spicatum* (Pursh) Scribn. and Smith]. Among the many forbs, storksbill [*Erodium cicutarium* (L.) L'Her.], goatsbeard (*Tragopogon dubius* Scop.), Douglas knotw (*Polygonum douglasii* Greene), ground smoke (*Gayophytum diffusum* Torr. and Gray), and prickly lettuce (*Lactuca serriola* L.) are the most common. Big sagebrush (*Artemisia tridentata* Nutt.) and rubber rabbitbrush [*Chrysothamnus nauseosus* (Pall.) Britton] oc as solitary plants scattered throughout the bitterbrush stand.

We estimated bitterbrush yield in November 1967 by (1) counting all live bitterb shrubs in the measured 1.43-ha (3.53-acre) stand; (2) clipping, ovendrying, and weigh the current annual growth from 34 randomly chosen sample shrubs; and (3) applying the mean ovendry yield to the total number of live shrubs. We also measured the total height and crown diameter of each sample shrub.

FINDINGS

Bitterbrush density in the planted stand was 1,877 live shrubs per hectare (760 per acre). Heights of individual shrubs before clipping averaged (±SD) 1.07 ± 0.15 m (3.51 ± 0.49 feet); crown diameters averaged 1.26 ± 0.23 m (4.13 ± 0.75 feet). Mean ovendry yield per bitterbrush plant was 371 ± 133 g (0.82 ± 0.29 lb). Expressed on a unit-area base, the ovendry yield of bitterbrush was 696 ± 249 kg/ha (621 ± 222 lb/ac We are unaware of any published data on single-year bitterbrush yields that exceed th value. Blaisdell (1953) reported a bitterbrush yield of 348 kg/ha (311 lb/acre) in southeastern Idaho. Hormay (1943) suggested that some bitterbrush stands in Californ might yield as much as 1 010 kg/ha (900 lb/acre).

We described soil profiles at three locations in the planted stand. Soil characteristics are summarized as a composite profile in table 1. The soil is relatively young, coarse textured, well-drained, moderately deep, and slightly acidic. A large gravel fraction was found throughout the soil profile. Clay fractions were consisten low. Hormay (1943) and Nord (1965) found similar soil characteristics on the most productive bitterbrush sites in California.

Bitterbrush growth is known to be sensitive to both seasonal and annual fluctuations in precipitation (Garrison 1953, Shepherd 1971). Therefore, we examined local weather records for a possible explanation of the unusually high yield observed in 1967. Monthly means of precipitation and temperature immediately preceding and during the growing season are compared with long-term records in table 2. Weather data were summarized from U.S. Weather Service records at Arrowrock Dam, located about 10 km (6 miles) from the bitterbrush planting site and at about the same elevat

Table 1.--*Physical characteristics of a composite soil profile, South Fork Boise River, Idaho*

Horizon	Depth	pH	Moisture retained at two tensions 1/3 bar	15 bars	Particle size distribution Gravel	Sand	Silt	Clay
	cm (Inches)		- - - - - - - - - -		*Percent* - - - - - - - - - -			
A_{11}	0-5 (0-2)	6.3	12.6	5.6	44.5	76.7	18.2	5.1
A_{12}	5-20 (2-8)	5.8	10.8	4.6	44.2	75.7	18.4	5.9
AC	20-40 (8-16)	5.6	10.7	4.7	45.7	75.5	17.1	7.4
C_1	40-60 (16-24)	5.6	9.5	4.3	45.3	76.8	16.3	6.9
C_2	60-90 (24-36)	5.7	10.6	4.1	46.8	77.4	15.4	7.2
C_3	90+ (36+)	5.7	9.2	4.1	48.1	78.4	14.6	7.0

Table 2.--*Comparison of 1966-67 weather data with long-term records, Arrowrock Dam, Idaho*

Month	Precipitation Total	Departure from normal	Temperature Mean	Departure from normal
	- - - - - *cm* - - - - - - -		- - - - - - - °C - - - - - - -	
Oct.	1.2	-2.0	8.9	-1.5
Nov.	6.8	+0.9	5.0	+2.4
Dec.	6.2	-0.9	-0.7	+0.8
Jan.	9.9	+2.8	0.2	+4.4
Feb.	2.6	-4.0	2.0	+3.3
Mar.	2.5	-2.9	4.2	+1.0
Apr.	3.9	+0.1	5.4	-3.7
May	1.6	-2.0	12.7	-1.0
June	6.9	+4.1	17.2	-0.4
July	0.3	-0.4	24.4	+1.0
Aug.	0.0	-0.4	24.4	+2.1
Sept.	1.4	+0.2	19.1	+2.0
Year	43.3 (17.1 inches)	-4.5 (-1.8 inches)	10.2 (50.4°F)	+0.9 (+1.6°F)

A relatively warm winter was followed by a cool spring marked by below-average precipitation except for the month of June, during which rainfall was more than double the long-term average. Most of the June rainfall was from four thunderstorms that were distributed throughout the month (June 1, 6, 10, and 21). More than 1 cm (0.394 inches) of rain fell during each of the four storms. Measurable rainfall occurred on each of 12 days during the month. Total precipitation during June was the second highest on record.

We suggest that the exceptionally high yield of bitterbrush observed in 1967 was the result of (1) a cool spring and abnormally high rainfall in June, resulting in unusually high soil moisture, and (2) soil and site characteristics conducive to bitterbrush growth. Most of the current shoot growth of bitterbrush occurs during June in southwestern Idaho.

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Research Note

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LIGHT BURNING AND THE NUTRIENT VALUE OF FORAGE

N. Stark[1]

ABSTRACT

Slash burning in a clearcut under conditions producing very light to light burn intensities (<150°F or 66°C) for a short duration did stimulate resprouting, but resulted in almost no enrichment of biologically essential nutrients in the foliage. Burns of this low temperature range are not suitable for improving the quality and quantity of browse. Exceedingly dry soil conditions during the summer months appear to have resulted in low nutrient contents in clip plots where plants were crowded and dense, but not in controls where spacing was wider.

KEYWORDS: Prescribed burning, wood residues, forage nutrients,
browse stimulation.

The use of fire to stimulate browse and subsequently grazing is an accepted practice in many parts of the world (Chamrad and Dodd 1972; Biswell 1972; Kirsch and Kruse 1972). Fire is especially beneficial in stimulating grass production for grazing animals. Fire usually increases the quality and quantity of browse in forest ecosystems (Stark and Steele 1977). At what temperature is a fire too light to release enough nutrients to stimulate increased foliar nutrients? A light fire that crawls through the litter may surface, kill the herbs and some brush, and stimulate resprouting; but the nutrients released may not reach the plant roots. They may be absorbed by the litter, soil organisms, or surface soil.

Silvicultural treatments of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) at the Coram Experimental Forest near Glacier National Park were designed to use fire for slash reduction and site preparation. The overall study is a large scale effort involving several silvicultural treatments, skyline harvesting methods, meteorology, soil water chemistry, microbiology, road construction technology, and economic implications.

The portion reported here covers foliar nutrient contents the first 2 years after burning. Other studies have shown increases in the per gram foliage content of nutrients within 2 years following burning (Stark and Steele 1977).

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[1] This research was conducted as a cooperative project between the Intermountain Forest and Range Experiment Station, Ogden, and the School of Forestry, University of Montana, Missoula. Dr. Nellie Stark is Professor, School of Forestry, University of Montana.

The moderately productive soils have an ash-influenced horizon, but are not trul andic. They are generally andeptic cryochrepts at 3339 to 6370 ft (1018 to 1942 m) elevation. Argillites, or sandy or quartzitic argillites overlie the limestone or do mite of the Siyeh formation (Klages and others 1976). The topography is steep (35-4 percent) with long slopes.

For the specific study site, the habitat type is *Abies lasiocarpa/Clintonia uni* (ABLA/CLUN) (Robert D. Pfister, personal communication). The vegetation was largely Douglas-fir and western larch (*Larix occidentalis* Nutt.).

The area receives about 31 inches (787 mm) of precipitation annually. Much of i is snow. Extreme winter air temperatures reach -29°F (-34°C) and summer maxima reach 90°F (33°C). The mean annual temperature is 42.8°F (6°C). The area is not extremely windy, but occasional windstorms do uproot trees.

The organic layer is variable in depth, often reaching 7.9 inches (20 cm) where old logs have decayed. There was no evidence of recent fire on the area where study of foliage nutrient levels was to be intensive.

METHODS

Only the hottest of the light burns was studied. This was selected for studies nutrient accumulation in the foliage. The burn in the fall of 1975 was light becaus of persistent rain. Litter had only 2 or 3 days to dry between storms. Temperature dropped noticeably in September. As a result, fuels were cold and wet. Fine standi twigs burned well. Logs charred, but did not burn. Litter burned to mineral soil i a few spots. Soil temperatures were measured by Raymond Shearer using Tempilaq[2] mel compounds. Other data included duff reduction plots using bridge spikes to mark the original duff depth (Artley 1978). One and 2 years after the burn, in August of 197 and again in August 1977, 50 plots 12.2 x 12.2 inches (31 x 31 cm) were clipped of a green, live vegetation from very lightly burned spots. Another 50 plots of the same size were clipped from lightly burned areas. In the control areas, another 50 rando located plots were clipped in the same manner as for the burns.

In 1976, only 10 foliage samples from each of five herb and shrub species were collected from very lightly and lightly burned areas. Another set of 10 samples each of shrub and herb foliage was collected from the adjacent control area. These sampl were analyzed to determine if foliage from burned areas showed significantly differe levels of biologically essential nutrients for the same species.

The clip plot samples were air dried, ground to 0.039 inches (1 mm), and homoge The leaves of the individual shrub or herb species were dried, ground in the same manner and analyzed. One gram samples from clip plots or foliage were ashed at 977° (525 ± 2°C) for 2 hours, taken up in heated 6N HCl, and made to 100 ml volume at roo temperature (Black 1965). These samples were analyzed by atomic absorption spectros for calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (sodium (Na), and zinc (Zn) (Techtron 1974). One ml of 5 percent La was added for th analysis of Ca and Mg. Phosphorus (P) was analyzed colorimetrically using the ammon molybdate method (Black 1965).

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

The data were processed statistically using t-tests and absolute concentrations were graphed in micrograms per gram on polygrams with 8 axes. Soil temperatures during the burn and summer soil moisture (H. Newman, personal communication) to 3.2 ft (1 m) depth were studied to explain plant behavior. Species composition was measured before, but not the year after a burn (Jack Schmidt, personal communication).

RESULTS AND DISCUSSION

The individual species studied, *Rosa* sp., *Spiraea betulifolia* Pall., *Arnica cordifolia* Hook., *Vaccinium membranaceum* Dougl., and *Berberis repens* Lindl. showed no significant (5 percent) levels of nutrients accumulated on very lightly or lightly burned sites. Nutrient levels for 10 biologically essential nutrients were variable, but usually within the range of variation of the controls. Some species were significantly different from others in nutrient content, especially calcium.

Likewise, the clip plots showed no significant (5 percent) levels of excess nutrients resulting from burn treatments the year after a fire. Figure 1 shows the levels of nutrients from the clip plots in the control, very light burn, and light burn materials. The figures appear as averages, and significant levels of manganese did occur on very lightly and lightly burned clip plots compared to manganese in control clip plots. All other elements were variable, but within the range of concentrations found in the controls.

In the first year after burning, the vegetation on control clip plots and on light and very light burns showed relatively high levels of Zn in the foliage. Manganese was also high in the vegetation. In 1976, the soil was quite wet and in both the burn and control moisture content was favorable for growth (19 percent and 16 percent, respectively). Although there was more moisture in the soil in the clearcut, moisture did not appear to limit growth or nutrient uptake that year. Microsite variability makes it difficult to interpret these data more closely.

In 1977, the second year following burning, zinc and magnesium levels decreased (table 1). For all elements, except iron, the nutrient content was higher in control plot foliage than in foliage from either lightly or very lightly burned plots. Specifically, K, Mg, Mn, N, Na, and P content and total cations were all significantly higher in control foliage as compared to foliage grown on lightly burned sites. Foliage from very light burns was significantly higher in iron and percent ash than that from the light burn (5 percent level, table 1).

These differences are hard to explain. The answer may be that available soil moisture was low during the dry 1977 summer. In July, the root zone 3.2 ft (upper 1 m) in control plots had too low (7.8 percent) moisture to maintain good solution of nutrients. Soils in the clearcut had about 8.4 percent moisture in July, which is also very low. The presence of trees and shrubby vegetation on the undisturbed site drew the available soil moisture down to zero, which could explain the change in foliar zinc and magnesium. Less water would mean that these nutrients were less available than in a wet year, so lower overall foliar levels were reached. The sodium level in foliage on control sites was higher in the dry year than in the wetter year, which verifies the low total moisture measurements. Sodium availability is closely tied to soil moisture. Magnesium and potassium were higher in control clip plots than in clip plots from either burn intensity in the dry year. These elements would be more concentrated in the soil solution on a milligram/liter basis than in a wetter year. Unfortunately, there was not enough mobile water in the soil for chemical analysis; so concentration effects had to be interpreted on the basis of experience. Zinc and manganese would be quite tightly bonded to colloids in a dry soil and would not be readily freed. The standard deviations for the content of elements in foliage from clip plots are understandably high since each clip plot had a different species composition (table 1).

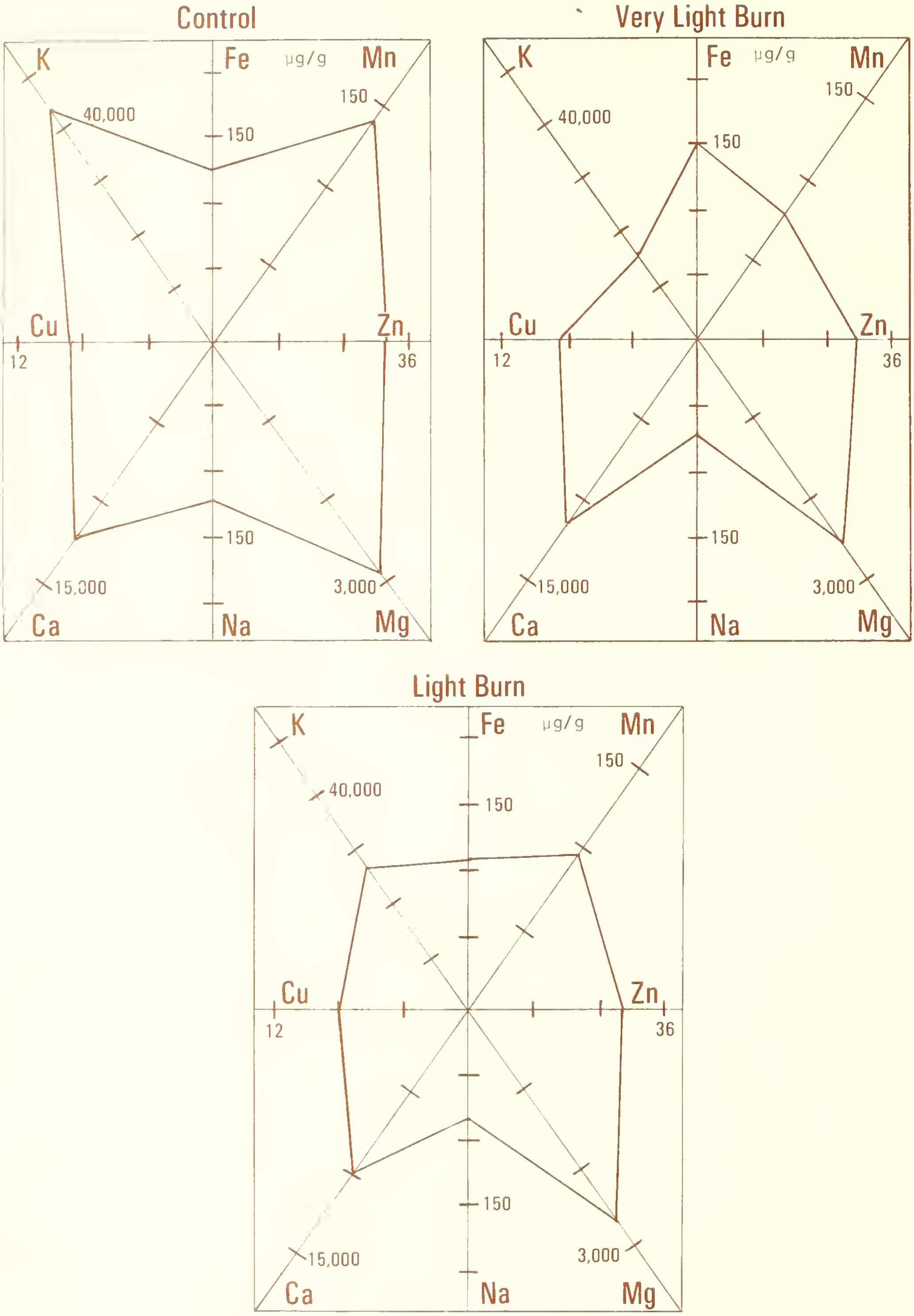

Figure 1.--Total nutrient levels in foliage and stems of controls, light, and very light burns on clip plots on the Coram Experimental Forest.

Table 1.--*Treatment averages and standard deviations for control and 2 burn treatment clip plot vegetation, and statistical comparisons of elemental differences among treatments by element (5 percent level)*

	Ca	Cu	Fe	K	Mg	Mn	N	Na	P	Zn	Percent ash
Control											
$\bar{x}$	10127	[1]9.9	233	[1]42445	[1]2989	[1]133	[1]13622	[1]123	[1]10888	30	10.8
sd	1979	1.7	464	15345	821	87	2351	17	2687	7.5	2.9
Very light burn											
$\bar{x}$	11691	8.3	[2]156	[2]28280	2486	80	10297	70	9196	28	[2]9.7
sd	3292	1.0	89	10739	577	33	1352	22	2230	9.8	2.4
Light burn											
$\bar{x}$	9860	[3]8.0	[3]107	[3]25080	2768	96	13216	[3]78	[3]8982	29	[3]7.7
sd	2749	1.9	43	13650	845	61	2768	24	2334	8.2	2.9

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[1] These control averages are significantly greater than the corresponding very light averages at the 5 percent level.

[2] These very light averages are significantly greater than the corresponding light averages at the 5 percent level.

[3] These light averages are significantly less than the corresponding control averages at the 5 percent level.

The foliage from control soils was much higher in nutrients than the foliage from either burn treatment. Resprouting on the burned sites was very vigorous in 1976 after the autumn (1975) fires. Water was abundant, but the burns were very light and had not released large quantities of nutrients; so the nutrient levels in the vegetation were not extremely high. (Few nutrients were shared by a large number of plants per unit area.)

If large amounts of plants existed per unit area in the dry summer of 1977, soil nutrient levels would be low because of the low water content. Competition would be intense; so lower concentrations of nutrients would be available to plants. On the control soils, water was so scarce that the lower density of plants and roots had access to higher absolute concentrations of some elements, such as potassium and manganese, but slightly less total water. Zinc and manganese were readily complexed and scarce in both systems. Iron and copper levels in foliage did not change appreciably between the 2 years. Biomass data were not taken in 1977; so that it is impossible to test this hypothesis against weights of foliage per square meter. Dry conditions in 1977 would have been exaggerated on the soil surface because of exposure and heat. This would retard decay and nutrient recycling.

Although there is nothing in the data to prove conclusively that the available soil water produced the measured foliar nutrient differences, the explanations are logical and supported by previous unpublished observations by the author.

Even if the soil had not been so dry in 1977, it is doubtful that the plants growin in the burns could have accumulated significant concentrations of elements from such light burns. Studies on the Lubrecht Experimental Forest (Stark and Steele 1977) showed that surface soil temperatures usually must reach 572°F (300°C) for significant releases of nutrients that may show up in concentrations in the foliage.

CONCLUSIONS

Fires of low intensity (surface soil <138°F (59°C)) are not likely to produce improved nutrient quality of the foliage, although resprouting may be stimulated. Drought reduces plant growth response to fire.

Litter temperatures did not exceed 150°F (66°C) at 1.9 inches (5 cm) depth on this clearcut. From soil chemistry and foliar data, it is resonable to assume that a burn must exceed 150°F (66°C) to produce measurable foliar nutrient concentrations. In a previous study, significant nutrient concentrations were found in some foliage where burns had exceeded 572°F (300°C). If the objective of burning is to stimulate browse species and improve the quality of browse, not just to initiate resprouting, it would appear that burns should be planned when surface soil temperatures will exceed 572°F (300°C). No studies were made on browse use of this area by large game animals, but the scarcity of tracks and scats suggest that this level of burn and human activity in the area do not attract herds of large game animals.

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Research Note

USDA FOREST SERVICE INT-281
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
507-25th STREET, OGDEN, UTAH 84401

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A COMPARISON OF THE NUTRIENT CONTENT OF ROCKY MOUNTAIN DOUGLAS-FIR AND PONDEROSA PINE TREES

James L. Clayton
Debora A. Kennedy[1]

ABSTRACT

Data on the content of nitrogen, phosphorus, sulfur, sodium, potassium, calcium, and magnesium in Douglas-fir and ponderosa pine trees are presented for the Silver Creek Study Area, in the southwestern Idaho batholith. Suppressed, intermediate, and dominant trees of each species were cut and sampled from two habitat types in the study area. Needles (stratified by age), bark, heartwood, and sapwood (stratified by bole size), and branches (stratified by branch size), were analyzed for the elements of interest. No significant differences in chemical content between habitat types were detected for either species. Interspecific differences in chemical concentration were found in one or more elements for each plant part. Trends in elemental concentration over needle age, bole size, and branch size were also suggested by the data.

KEYWORDS: plant chemistry, forest nutrition, *Pseudotsuga menziesii*, *Pinus ponderosa*

INTRODUCTION

We are currently conducting research in the Silver Creek Study Area, southwestern Idaho batholith, to assess the effects of timber harvesting on the environment. The Silver Creek Study Area, located approximately 70 miles (110 km) north of Boise, Idaho, is typical of a large portion of the Idaho batholith. The area has steep slopes and coarse-textured soils formed from granitic parent materials. As a result, moderate-to-high erosion potentials exist following disturbances associated with logging and road construction.

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[1] Research soil scientist and chemist, respectively, located at Boise, Idaho. The authors are indebted to Arthur R. Tiedemann and Nancy A. Mulligan of the Shrub Sciences Laboratory, Provo, Utah, for assistance in the sulfur analyses.

One study involves computation of nutrient losses from the watersheds as a result logging. For this study, we require data on the nutrient content of ponderosa pine (*Pinus ponderosa* Laws), and of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* [Mirb Franco var. *glauca* [Beissn.] Franco), the two major timber species harvested. In this paper, we present data on the nitrogen, phosphorus, sulfur, sodium, potassium, calcium and magnesium content of these two species.

OBJECTIVES

This study was conducted to quantitatively describe and compare the aboveground chemical content of nutrient elements in ponderosa pine and Douglas-fir trees, stratif by plant part and habitat type. In addition, this study will provide a data base need for computing nutrient budgets for the experimental watersheds following various loggi treatments.

METHODS

Ponderosa pine and Douglas-fir are the two principal tree species in the Silver Creek Study Area. They generally coexist in mixed stands and in a variety of habitat types. We stratified our sampling to reflect the driest and moistest habitats as indi ted by the common habitat types in Silver Creek. (For a discussion of habitat types a their nomenclature as used here, see Daubenmire and Daubenmire 1968, or Pfister and others 1977.)

Site I is a Douglas-fir/elk sedge (PSME/CAGE) habitat type, ponderosa pine phase, a relatively dry type. Site II is a subalpine fir/blue huckleberry (ABLA/VAGL) type, a relatively moist type. This site contains ponderosa pine and so is probably warmer than the typical subalpine fir/blue huckleberry site that does not support this specie Steele and others (in press) estimated that the yield capability for the PSME/CAGE type ranges from 40 to 95 ft^3/acre/yr (2.8 to 6.7 m^3/ha) with a mean of 70 ft^3/acre/yr (4.9 m^3/ha). Similarly, they estimated the yield capability for the ABLA/VAGL type to range from 60 to 90 ft^3/acre/yr (4.2 to 6.3 m^3/ha) with a mean value of 75 ft^3/acre/yr (5.3 m^3/ha). These differences principally reflect the differing moisture and temperature characteristics of the two habitat types.

Soils on the two sites are morphologically similar. Both soils are classified as cryorthents: weakly developed soils with A and C horizons over bedrock at 20 to 30 incl (50 to 76 cm). Gravelly loamy sand and sandy loam textures predominate.

At each site, we selected three trees of both species, one in each of the followi crown dominance classes: suppressed, intermediate, and dominant. The actual size and for each tree are shown in table 1.

Table 2.--*Size and age of each tree sampled. Age was determined by ring count at stump height*

Species	Habitat type			
	PSME/CAGE		ABLA/VAGL	
	d.b.h.	age	d.b.h.	age
	Inches	*Years*	*Inches*	*Years*
Ponderosa pine				
Suppressed	8	59	12	86
Intermediate	16	160	19	100
Dominant	26	197	31	232
Douglas-fir				
Suppressed	11	67	14	89
Intermediate	19	76	23	145
Dominant	20	134	30	235

Each tree was cut and sampled in August 1977 in the following manner:

1. At 1/8, 3/8, 5/8, and 7/8 of the total length of the tree bole, we cut a 3-inch-thick cross section and separated heartwood and sapwood.

2. From the suppressed and dominant trees, we took a bark sample at the same four locations along the bole.

3. From the subordinate trees, we sampled several limbs of two size classes, <1/4-inch diameter and 1/4- to 1-inch diameter. From the intermediate trees, we sampled several limbs 1 inch to 3 inches in diameter. From the dominant trees, we sampled several limbs 3 to 6 inches in diameter.

4. From the intermediate trees, we sampled needles from that year (1977) and from the two previous growing seasons (1976 and 1975). (In the rest of this paper, needles will be referred to as 1-year-old, 2-year-old, or 3-year-old needles.) All samples were placed in plastic bags and brought back to the laboratory for sample preparation and chemical analysis.

LABORATORY TECHNIQUES

In the laboratory, the samples were allowed to dry in the air for 2 weeks. At the end of this period, the samples were dried in an oven for 24 hours at 167°F (75°C). Subsamples were taken from each ovendried sample and ground in a Wiley[2] mill to pass a 0-mesh screen.

Samples of heartwood, taken from four locations along the tree bole, were batched efore grinding. The same subsampling and batching was done on sapwood and bark samples rior to grinding.

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

Samples were digested in a perchloric acid-nitric acid mixture (Johnson and Ulric 1959) and analyzed for calcium, magnesium, potassium, sodium, and total phosphorus. Calcium and magnesium were analyzed by atomic absorption; sodium and potassium by flam emission; and total phosphorus by the molybdate blue-ascorbic acid method. A Kjeldahl digestion was used for total nitrogen and detected by a titrimetric procedure. Dried and ground tissue was analyzed for sulfur using a Leco induction furnace by the techni e of Tiedemann and Anderson (1971).

DATA ANALYSIS

Data presented are mean values of two analyses run on each digest. In addition, each plant part (for example, 1-year-old needles and branches <1/4 inch in diameter) wa digested in duplicate. Duplicate analyses of each digest were reanalyzed if the repor values varied by more than 5 percent for all elements except nitrogen and sulfur. Nitrogen analyses were reanalyzed if values varied by more than 8 percent; sulfur was reanalyzed if values differed by more than 10 percent.

We analyzed the data initially by graphical observation in the following manner: (1) for needles, plots of concentration over needle age were made for both species and and both habitat types; (2) for sapwood, heartwood, and bark, concentrations were plotted over tree diameter for both species and for both habitat types; (3) for branch concentrations were plotted over branch diameter for both species and for both habitat types.

Apparent differences between species and between habitat types were tested by Student's T-test. In some cases, apparent differences in the slope of concentration ov age (needles), or in tree size (heartwood, sapwood, and bark), or in branch size were tested by covariance analysis.

RESULTS AND DISCUSSION

Mean nutrient concentrations for both species by plant part are summarized in tables 2 and 3. The values given in these tables are stratified by needle age and by tree bole or branch size. Differences in nutrient concentrations of Douglas-fir and ponderosa pine that were significant at the 0.01 or 0.10 percent level are presented in table 4. The concentration of phosphorus in Douglas-fir branches is apparently greater than that in ponderosa pine branches, but this assumption was not tested because phosphorus content of the larger pine branches was below our detection limit.

Sodium concentrations in all plant parts for both species and for both habitat types are remarkably similar, ranging from approximately 0.037 to 0.056 percent by weight (tables 2 and 3).

Concentrations of potassium, calcium, and magnesium are consistently higher in sapwood of Douglas-fir than in heartwood. Comparisons of these same elemental concentrations in sapwood and heartwood of ponderosa pine did not show the same trends (tabl 2 and 3).

Table 2.--*Nutrient content of ponderosa pine, data combined from two sites. All values are reported as percent by weight*

Plant part	Element						
	Sodium	Potassium	Calcium	Magnesium	Phosphorus	Nitrogen	Sulfur
Needles							
Current year	[1]0.047	0.829	0.108	0.109	0.191	1.48	0.114
1 year old	.035	.722	.194	.114	.136	1.58	.106
2 years old	.031	.642	.225	.098	.151	1.60	.105
Mean	.037	.739	.176	.107	.159	1.55	.108
Sapwood							
Suppressed tree	.044	.057	.076	.026	[2]	0.524	.007
Intermediate tree	.060	.045	.049	.017		.286	.015
Dominant tree	.059	.053	.056	.014		.304	.011
Mean	.054	.052	.060	.019		.371	.011
Heartwood							
Suppressed tree	.050	.033	.141	.032	[2]	.291	.005
Intermediate tree	.054	.039	.089	.028		.323	.005
Dominant tree	.051	.026	.092	.024		.315	.007
Mean	.051	.033	.100	.028		.313	.005
Branches							
<1/4-inch diameter	.043	.250	.383	.095	.043	.829	[3]
1.4 to 1 inch dia.	.049	.135	.296	.080	.033	.794	[3]
1 to 3 inches dia.	.047	.070	.604	.038	[2]	.381	.012
>3 inches diameter	.064	.066	.493	.035		.389	.008
Mean	.051	.130	.444	.061		.585	.010
Bark							
Suppressed tree	.055	.253	.349	.078	.033	.734	.052
Dominant tree	.056	.034	.323	.018	[2]	.509	.037
Mean	.056	.137	.337	.048		.621	.045

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[1] Each data point is the mean value of two separate digestions and duplicate analyses.

[2] Values were below the detection limit (0.01 percent) for all samples of sapwood and heartwood and for some branch and bark samples.

[3] Samples were not analyzed.

Table 3.--*Nutrient content of Douglas-fir, data combined from two sites. All values are reported as percent by weight*

Plant part	Element						
	Sodium	Potassium	Calcium	Magnesium	Phosphorus	Nitrogen	Sulfur
Needles							
Current year	[1]0.043	0.750	0.423	0.117	0.133	1.20	0.088
1 year old	.070	.631	.888	.147	.120	1.01	.090
2 years old	.037	.582	1.05	.153	.115	1.28	.082
Mean	.050	.655	.786	.139	.123	1.16	.087
Sapwood							
Suppressed tree	.042	.038	.059	.008	[2]	0.409	.011
Intermediate tree	.043	.033	.052	.006		.306	.018
Dominant tree	.042	.037	.057	.006		.296	.007
Mean	.042	.036	.056	.007		.337	.012
Heartwood							
Suppressed tree	.047	.016	.029	.003	[2]	.268	.005
Intermediate tree	.066	.013	.027	.003		.264	.013
Dominant tree	.050	.011	.022	.002		.269	.011
Mean	.055	.013	.026	.003		.267	.010
Branches							
<1/4-inch diameter	.055	.199	.578	.061	.073	.978	[3]
1/4 to 1 inch dia.	.044	.137	.928	.051	.049	.758	[3]
1 to 3 inches dia.	.072	.065	.541	.023	.017	.393	.011
>3 inches diameter	.050	.077	.646	.029	.021	.407	.012
Mean	.055	.120	.674	.041	.040	.628	.012
Bark							
Suppressed tree	.055	.126	1.38	.041	.036	.625	.015
Dominant tree	.055	.107	1.37	.034	.026	.727	.011
Mean	.055	.115	1.38	.038	.031	.676	.013

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[1] Each data point is the mean value of two separate digestions and duplicate analyses.

[2] Values were below the detection limit (0.01 percent) for all samples of sapwood and heartwood.

[3] Samples were not analyzed.

able 4.--*Comparison of nutrient levels for plant parts of ponderosa pine and Douglas-fir tested by Student's T-test. Data taken from tables 2 and 3*

lant part	Element	Concentration greater in	Significance level
eedles	Calcium	Douglas-fir	0.01
	Magnesium	Douglas-fir	.01
	Nitrogen	Ponderosa pine	.01
	Sulfur	Ponderosa pine	.01
apwood	Potassium	Douglas-fir	.01
	Magnesium	Douglas-fir	.01
eartwood	Calcium	Ponderosa pine	.01
	Magnesium	Ponderosa pine	.01
ranches	Magnesium	Ponderosa pine	.10
	Calcium	Douglas-fir	.01
ark	Calcium	Douglas-fir	.01
	Sulfur	Ponderosa pine	.01

For both species, relationships exist between the nutrient content and the age of eedles. Calcium increases with needle age for both species (fig. 1). In addition, the ate of increase in calcium content with increasing needle age is greater for Douglas-fir han for ponderosa pine. This increase is apparent by inspection and was highly signiicant when tested by covariance analysis. For the common model (habitat type not onsidered), F = 22.94, f = 1, 20. Potassium and phosphorus decrease with the age of the eedles for both species (figs. 2 and 3). There appears to be no difference in the slope r mean concentration between the two species.

Similar relationships can be drawn when nutrient content is compared with tree iameter. In sapwood, magnesium and nitrogen tend to decrease as tree diameter increases figs. 4 and 5). For bark samples, the potassium and total phosphorus tend to decrease s tree diameter increases (figs. 6 and 7). These relationships were not tested for ignificance because the sample size was small and this study was not designed to test his hypothesis.

When nutrient content and size class of branches are compared, magnesium, potassium, nd nitrogen all decrease with increasing size class (figs. 8, 9, and 10). Magnesium, otassium, and nitrogen appear to reach a base level at from 0.02 to 0.04 percent, 0.05 o 0.10 percent, and 0.3 to 0.5 percent, respectively, when branch diameter exceeds inch (figs. 8, 9, 10).

There were no apparent differences in chemical composition of tree parts of the ame species when comparison was made between habitat types. The slightly greater yield apability in the more moist ABLA/VAGL type suggests that the standing crop nutrient ontent, expressed in kilograms per hectare, would be greater in this habitat type than n the drier PSME/CAGE habitat type. Such a conclusion is likely to be valid only for tands of mature trees that have attained maximum nutrient content.

Extraordinarily high concentrations of potassium were found in bark of the small onderosa pine from Site I. The results were consistent for two separate digestions nd duplicate analyses. Contamination is possible, but would have had to have happened o the bulk sample prior to subsampling, grinding, and digestion.

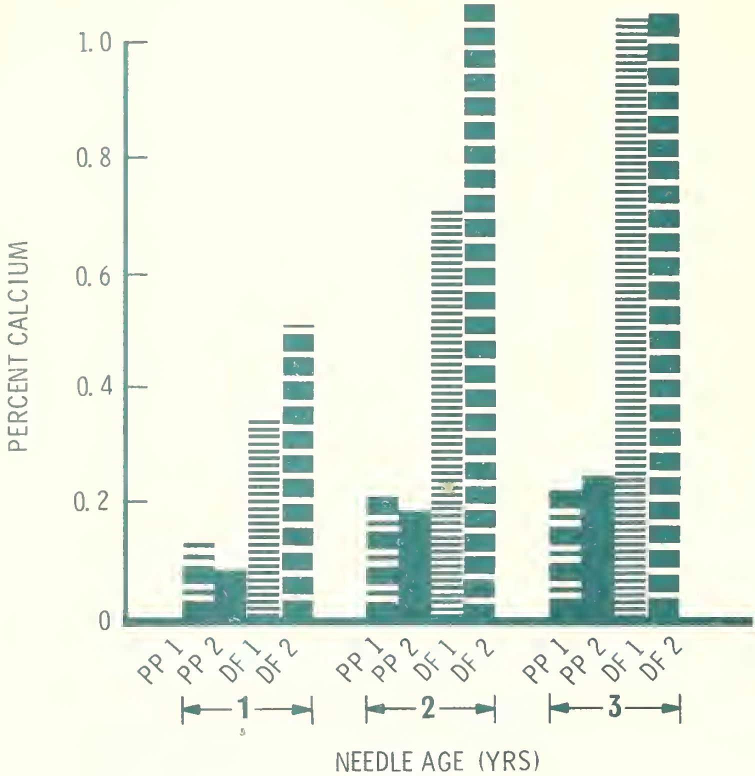

Figure 1.--Percent calcium in needles plotted over needle age, where 1 = current year (1977) needle growth. Data are presented for both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

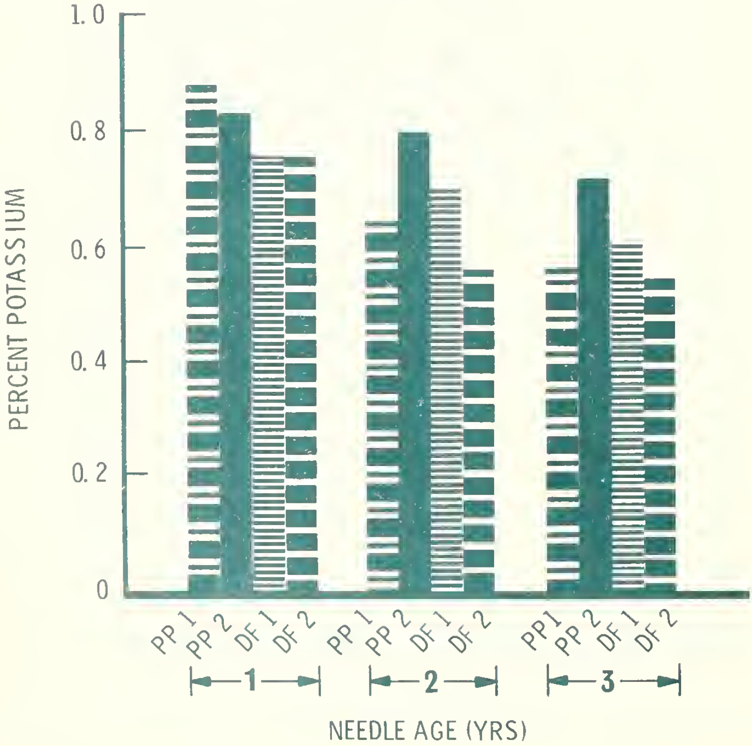

Figure 2.--Percent potassium in needles plotted over needle age, where 1 = curren year (1977) needle growth. Data are presented for both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

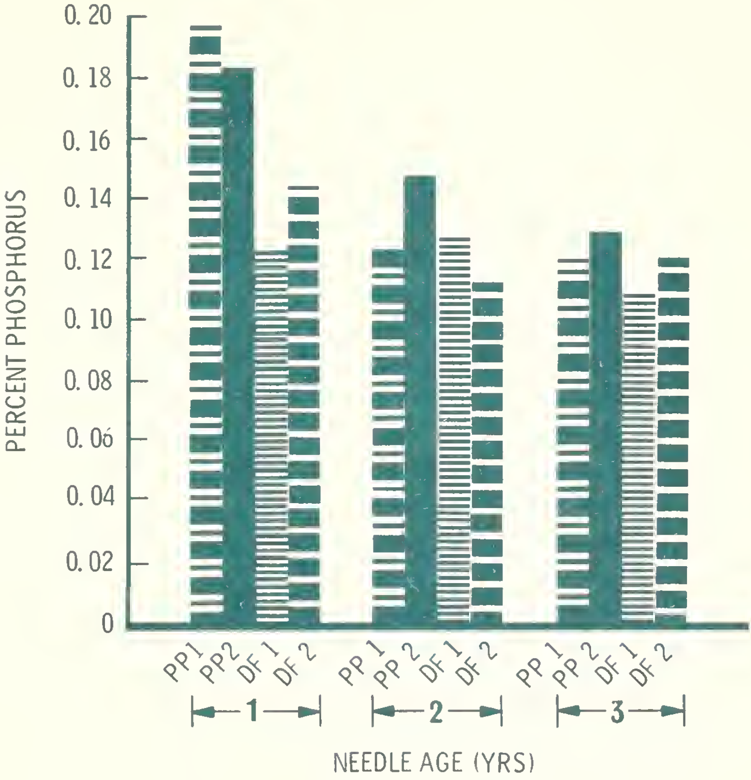

Figure 3.--Percent total phosphate in needles plotted over needle age, where 1 = current year (1977) needle growth. Data are presented for both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

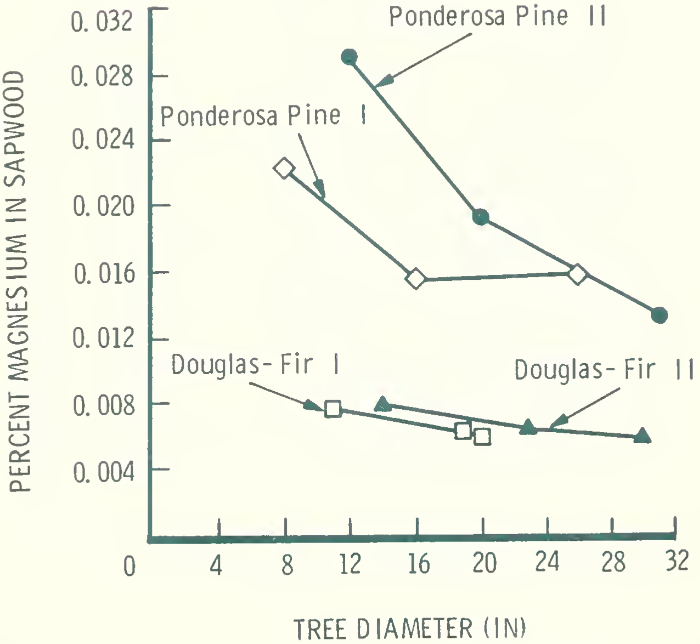

Figure 4.--Percent magnesium in sapwood plotted over tree diameter at breast height for both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

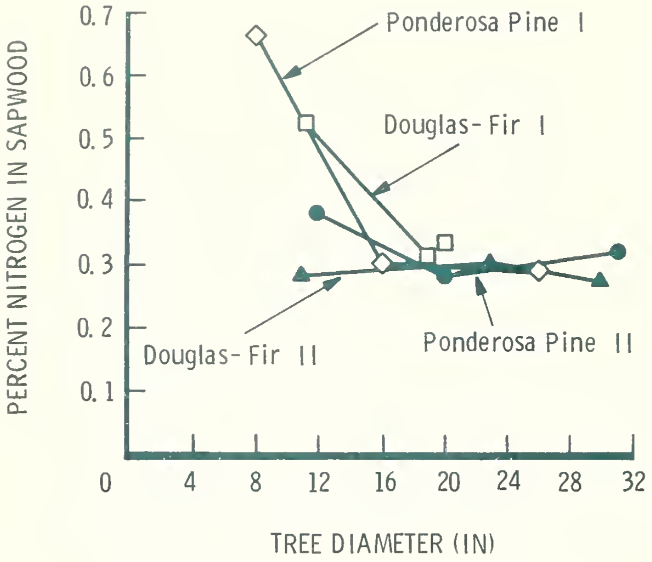

Figure 5.--Percent total nitrogen in sapwood plotted over tree diameter at breast height for both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

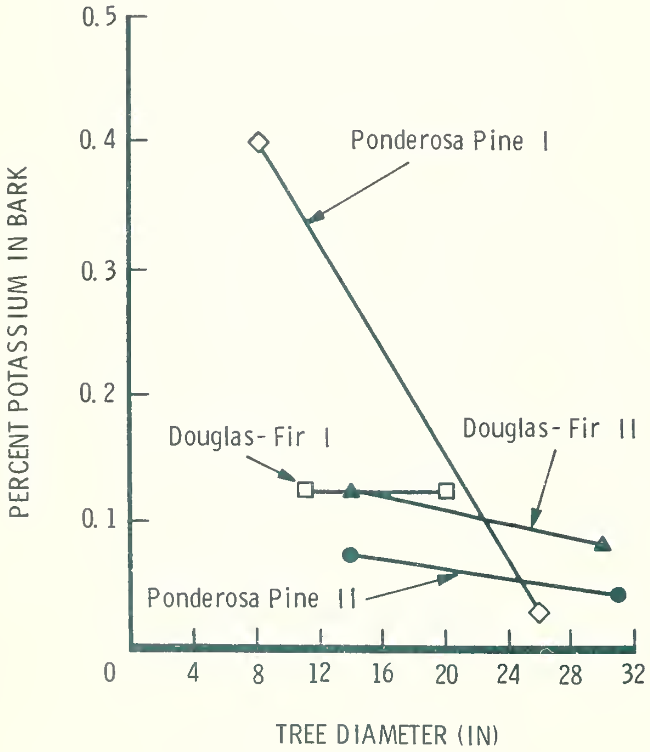

Figure 6.--Percent potassium in bar plotted over diameter at breast height for trees of both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

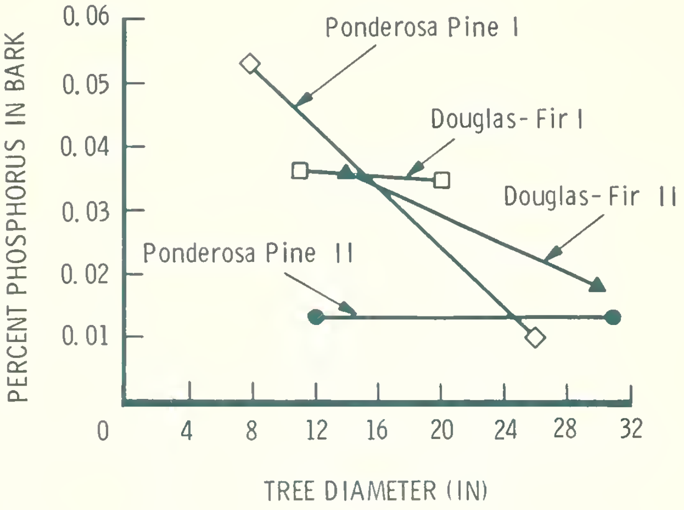

Figure 7.--Percent total phosphorus in bark plotted over diameter at breast height for trees of both species and both habitat types; I = PSME/CAGE and II = ABLA/VAGL. Each point represents the mean value of two separate digestions and duplicate chemical analyses.

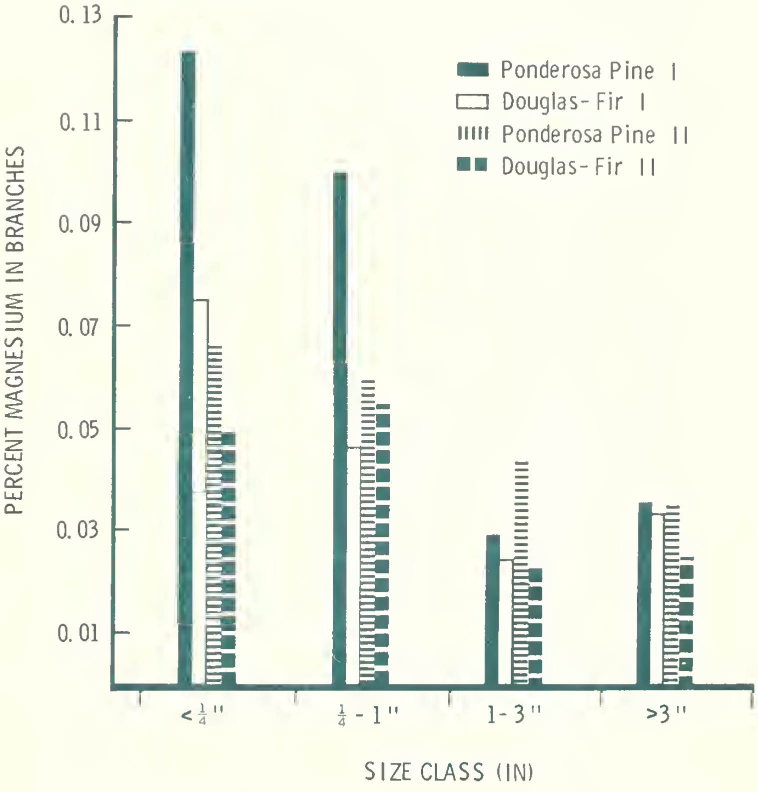

Figure 8.--Percent magnesium in branches plotted by branch size class. Each point represents the mean value of two separate digestions and duplicate chemical analyses. Site I is a PSME/CAGE habitat type and site II is a ABLA/VAGL habitat type.

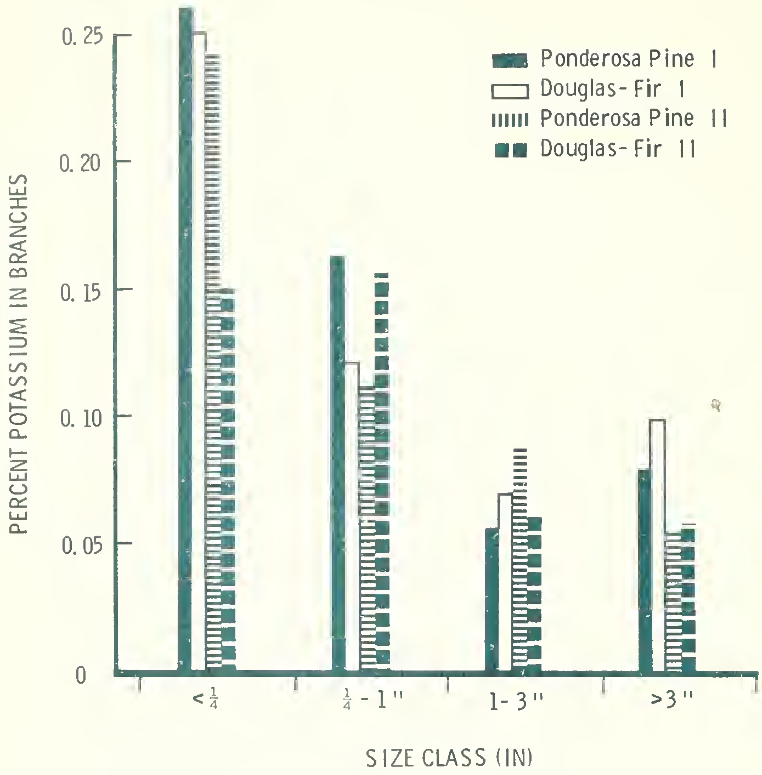

Figure 9.--Percent potassium in branches plotted by branch size class. Each point represents the mean value of two separate digestions and duplicate chemical analyses. Site I is a PSME/CAGE habitat type and site II is a ABLA/VAGL habitat type.

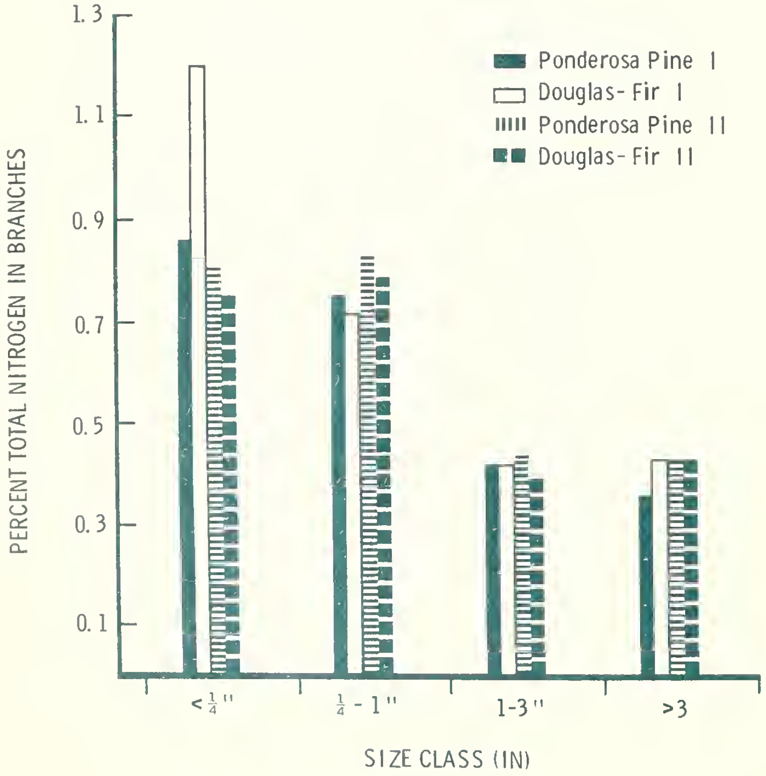

Figure 10.--Percent total nitrogen in branches plotted by branch size class. Each point represents the mean value of two separate digestions and duplicate chemical analyses. Site I is a PSME/CAGE habitat type and site 11 is a ABLA/VAGL habitat type.

Results of this study will provide a data base necessary for computing nutrient losses caused by removing the boles from logged units in the Silver Creek Research Area. Future plans include studies on rates of litter and slash decomposition in Silver Creek. Data from this paper will also be used to estimate nutrient gains to the soil from litter and slash decomposition when decomposition rate studies are completed.

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ROOTING STEM CUTTINGS FROM ASPEN SEEDLINGS

George A. Schier[1]

ABSTRACT

*Stem cuttings from two types of shoots on 2-year-old aspen (*Populus tremuloides *Michx.) seedlings were successfully rooted--spring shoots and shoots induced to develop by defoliation. Rootone F significantly increased rooting response in both types of cuttings. Only those cuttings from spring shoots treated with Rootone F rooted. There were significant differences between seedlings (genotypes) in rooting ability of cuttings from spring shoots.*

KEYWORDS: *Populus tremuloides,* Quaking aspen, adventitious roots, rooting stem cuttings, vegetative propagation.

The standard method for vegetatively propagating aspen (*Populus tremuloides* ichx.) is by rooting cuttings taken from young, succulent suckers (adventitious shoots) hat arise from excised roots (Schier 1978). This method is used because of the ifficulty in rooting aspen stem cuttings (Hicks 1971); however, a considerable amount f time and expense is involved in collecting roots and culturing suckers. It would e desirable if a procedure could be found for rooting stem cuttings.

Probably the best chance of success in rooting aspen stem cuttings is to obtain he cuttings from newly emergent shoots on seedlings. It is well known that cuttings rom juvenile trees can be rooted much more readily than cuttings from older or adult rees. In this study, cuttings from two types of shoots on seedlings--shoots elongating fter spring bud break and shoots induced to develop by defoliation--were tested for ooting ability.

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METHODS

Stem cuttings used in this study were obtained from 2-year-old aspen seedlings [mean height, 32 inches (82 cm)] growing in 1 gallon pots in a lathhouse (50 percent shading).

On April 21, 1978, 10 cuttings 1.38 to 2.76 inches (3.5 to 7 cm) in length were removed from the tops of elongating lateral shoots of each of 12 seedlings. All but the top three to five leaves were removed from each cutting. Five of the 10 cuttings from each seedling were treated by dipping 0.39 inch (1 cm) of the basal ends in Rootone F (Amchem Products, Inc.),[2] a commercial rooting powder containing four root promoting growth regulators[3] and a fungicide (Thiam[2]). The other five cuttings, the controls, were dipped in talc. The base of each was randomly inserted to a depth of 0.59 to 1.18 inches (1.5 to 3 cm) in a moist mixture of perlite and vermiculite (1:1) in a large tray. The tray was placed on a misting bench with heating coils [temperature of rooting medium, 80° ± 2°F (27° ± 2°C)] in a greenhouse, 66° to 79°F (18° to 26°C). The misting schedule ranged from 1 min every 5 min during the warmest part of the day to 1 min every 20 min during the night. After 28 days, the cuttings were lifted and number and length of roots on each were recorded.

A second flush of growth was induced in 30 aspen seedlings by defoliating them on June 30, 1978. On July 21, two to five cuttings were removed from the tips of elongating lateral shoots of each seedling. The cuttings had the same range in sizes and were treated in the same manner as the first experiment. Rooting methods were also the same. In this experiment, however, cuttings from all seedlings were combined and 60 randomly selected for treatment, 30 with Rootone F and 30 with talc. In the rooting tray rows of five cuttings treated with rooting powder were alternated with rows of five control cuttings. Root numbers and lengths were recorded after 4 weeks.

RESULTS AND DISCUSSION

Adventitious roots developed only on those cuttings from spring shoots that were treated with Rootone F (table 1). There was a significant difference (0.05 level) in rooting ability among cuttings from the 12 seedlings (genotypes) as shown by the variation in rooting percentages, numbers of roots, and root lengths. Variation in root lengths could have been due to time of root initiation and/or rate of root growth. The only evidence of vegetative growth on control cuttings was development of a callus at the cut ends.

The failure of untreated stem cuttings to root contrasts with the relatively high rooting capacity of untreated sucker cuttings from root segments. Of the more than 50 clones I have tested for rooting ability of sucker cuttings, rooting percentages of less than 25 percent were unusual. In no case did a clone fail to initiate roots.

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

[3] Napthylacetamide, 0.067%; 2-methyl-1-naphthylacetic acid, 0.033%; 2-methyl-1-napthylacetamide, 0.013%; and indole-3-butyric acid, 0.057%.

ble 1.--*Rooting of Rootone F treated cuttings taken on April 21, 1978, from elongating lateral shoots on 2-year-old aspen seedlings*

Seedling	Rooting	Mean roots per rooted cutting	Mean length of longest root
	Percent		*mm*
1	20	6.0	67
2	20	1.0	16
3	80	3.5	20
4	80	3.8	106
5	100	5.4	39
6	60	1.3	19
7	80	1.8	65
8	40	4.5	97
9	100	8.0	112
10	100	2.4	117
11	100	7.4	88
12	60	3.7	109
Mean	70	4.36	77.0

Roots were initiated on control cuttings from induced summer shoots but cuttings eated with Rootone F had a significantly greater rooting percentage and mean number roots (table 2).

There was no evidence of plagiotropic growth, characteristic of branches, in the oted cuttings. When the cuttings were transferred to individual containers, they ve rise to straight, well-proportioned seedling-like plants.

This study has shown that cuttings from newly emergent shoots on juvenile aspen n be rooted. The next step will be to determine the rooting capacity of shoots from anches of mature trees. Generally rooting ability declines with ontogenetical ing (Fortanier and Jonkers 1975).

Table 2.--*Rooting cuttings taken from elongating lateral shoots stimulated by defoliatin 2-year-old aspen seedlings on June 30, 1978*

Treatment	Rooting**	Mean roots per rooted cutting*	Mean length of longest root[N.S.]
	Percent		*mm*
Control	23.0	1.57	76.2
Rootone F	63.3	5.58	73.8

*significantly different at 0.05.
**significantly different at 0.01.
N.S. not significantly different.

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Locality		
›rcupine Creek	Chick Creek	Latham Springs
5,700	6,600	7,400
75	50	150
5	6	10
2,960	2,093	3,228
11	14	13
11.7	17.7	10.2
6.2	9.3	6.0

ion.

trees obviously taller than
ıin a relatively small pro-
. population. In fact, we
ıt one elite tree occurred in
ɛ populations.
terbreed, the genetic gain
heir progenies is express-

e:

on differential = mean
nce between selected and
:ted trees.

ıility = the proportion of
ıotypic variance that is
ly additive.

ıip, percent gains can be
e of heritabilities (fig. 4).
were as high as 0.5, seed-
terbreeding selected trees
ould be about 45 percent
ɪrogenies produced by the
n; even in relatively cold
m Springs), gains of 33
icipated. But most impor-
bilities are exceptionally
o 11 percent could be ex-
f selected trees at ages 10

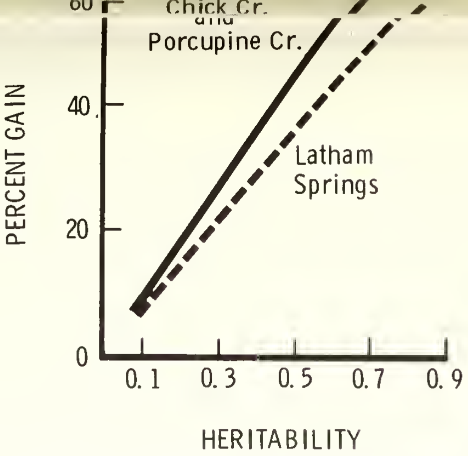

Figure 4.--Amount of genetic gain in height expected in progenies of elite trees for a range of heritabilities.

Even though heritabilities cannot be estimated without progeny tests, there is little doubt that substantial genetic gains can be made from mass selection in lodgepole pine. As shown by the relationship presented above, gains will accrue by maintaining a high selection differential in even-aged stands almost regardless of heritabilities. And, because of the young age at which lodgepole pine reaches sexual maturity, realization of gains is not too distant. All our selected trees were sexually mature. Grafted seed orchards could yield improved seeds within 5 years. Alternatively, seed orchards composed of progenies of selected trees would not only yield seeds in about 15 years, but would also yield extra increments of gain from family as well as individual tree selection. Regardless of the approach, mass selection will provide relatively inexpensive but efficient procedures for genetically improving the growth of lodgepole pine.

Intermountain Forest and
Range Experiment Station
U.S. Department of Agriculture,
Forest Service

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Genetic Gains From Mass Selection In Lodgepole Pine

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and S. P. Wells[1]

Lodgepole pine offers unique possibilities for tree improvement by mass selection. Juvenile growth is rapid, and sexual maturity is reached early. But most importantly, reproduction from serotinous cones after fire or timber harvest tends to be tremendously variable (fig. 1), dense (fig. 2), and of the same age. Individual trees (elite trees!) also express growth rates far above the average (fig. 3).

We explored the possible genetic gains from mass selection (selection of elite trees from a mass of reproduction) in three populations located on the Targhee National Forest near Ashton in southeast Idaho. As reflected by elevation, these populations represented contrasting environmental conditions (table 1). Our procedures involved: (1) verifying that both tall and short trees were the same age, (2) selecting elite trees, and (3) measuring the height of elite trees and the heights of trees within a 0.05-acre circle surrounding each elite tree. Mean height of elite trees represents the selected population; mean height of all trees represents the unselected population (table 1). We emphasize that no rigorous grading procedures were used to select elite trees; selected trees were not necessarily the tallest trees in each population,

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USDA Forest Service Research Note INT-283

Figure 1.--Phenotypic variation in crown form and growth rate. Tree ages from left to right: 20, 17, and 18.

Figure 2.--Dense even-aged reproduction.

Figure 3.--Elite trees in natural reprodu

Research Note

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INCIDENCE OF MOUNTAIN PINE BEETLE ABANDONED GALLERIES IN LODGEPOLE PINE[1]

Gene D. Amman[2]

ABSTRACT

Individual lodgepole pines have lower densities of attack by mountain pine beetles and a higher percentage of abandoned egg galleries in stands where beetle populations are low rather than high. Most trees contain some galleries having live beetles, as well as abandoned galleries. Females from galleries likely to be abandoned have been mated, discounting the unfertilized female as a reason for gallery abandonment. The amount and quality of blue-stain fungi carried by the beetle may influence success of gallery construction.

KEYWORDS: *Dendroctonus ponderosae*, *Pinus contorta*, egg gallery, pitch out

Mountain pine beetles (*Dendroctonus ponderosae* Hopkins) abandon many egg galleries after constructing only 1 to 2 inches on some lodgepole pine (*Pinus contorta* Douglas var. *latifolia* Engelmann) trees. This phenomenon was thought to be due to females not being fertilized (Amman 1975). In the study reported here, stands of lodgepole pine were surveyed and mountain pine beetle galleries examined to determine how common gallery abandonment is. A second objective was to determine incidence of fertilized females from galleries that have a high probability of being abandoned.

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METHODS

In September 1975, 3 to 6 weeks after the flight and attack period of the mountain pine beetle was completed, six stands of lodgepole pine on four National Forests--Bridger-Teton in northwestern Wyoming; Sawtooth in south-central Idaho; Targhee in southeastern Idaho; and Wasatch in northern Utah--were surveyed for trees infested by the beetle. A systematic random sample consisting of either 20 or 40 one-fourth acre (0.1 ha) plots was used where beetle populations were high [1.5 or more trees infested per acre (3.75/ha)] and a 100 percent cruise was used where populations were low [less than one tree infested per acre (2.5/ha)]. Attacked trees were tallied by diameter at breast height (d.b.h.), examined, and classed into three categories: (1) abandoned trees--greater than 50 percent of galleries abandoned or likely to be abandoned; (2) strip-attacked trees--a vertical strip of the trunk covered with galleries; and (3) mass attacked trees--entire lower bole covered with galleries. Trees that were strip attacke and abandoned, or from which beetles were pitched out, were not killed whereas those that were mass attacked were killed.

In both 1975 and 1976, trees where large proportions of galleries were expected to be abandoned were examined. Abandoned galleries have characteristic whitish pitch tubes an unobstructed opening to the gallery, and little or no fresh boring frass. Only the lower boles of the trees, where attacks can be found consistently, were examined. When few trees having pitch out or abandoned galleries occurred on the plots, additional off-plot trees were added to increase the sample size. Ten galleries were examined on the lower 6 feet (1.8 m) of the bole of each tree; however, fewer than 10 attacks occurred on some trees.

Data recorded from each gallery were: (1) length of gallery, (2) female present or absent, (3) male present or absent (4) eggs present or absent, and (5) beetles entangled in pitch within the gallery or in the pitch tube. When two beetles were in the same gallery, one was considered to be male. Where no male was found but eggs were present, the male was assumed to have left the gallery after fertilizing the female. This assumption seems reasonable because less than 2 percent of the females are fertilized prior to emergence and attack (McCambridge 1970). In addition, reemergence of females after completing an egg gallery is uncommon in the study areas.

In 1977, 20 females were removed from galleries likely to be abandoned. Sex of beetles was determined by criteria recommended by Lyon (1958). The spermathecae were removed, placed on glass slides, covered with cover slips, and crushed to release sperm. The presence or absence of sperm was determined by using a compound microscope (670 magnification). General observations of muscles and ovaries were noted.

RESULTS AND DISCUSSION

Abandoned trees.--Surveys of lodgepole pine stands showed that abandoned trees and those from which beetles were pitched out constituted 11 to 53 percent of the infested trees. Higher proportions of infested trees appear to be abandoned in plots having low beetle populations, for example on the Bridger and Sawtooth National Forests, than plots having high populations such as the Targhee and Cache (table 1). The Wasatch (high population) and the Teton (low population) did not fit this pattern well. The Wasatch had a fairly active infestation but the beetle population suffered heavy mortality during development due to drying of the trees, thus yeilding more females (71 percent) than males (29 percent) (unpublished data from life tables studies, Research Work Unit 2201, Intermountain Forest and Range Experiment Station, Ogden), a low population characteristic. The Teton had several large infested trees, consequently a sex ratio (60 percent ♀; 40 percent ♂) more typical of high populations was obtained.

Table 1.--*Types of mountain pine beetle infestations found in lodgepole pine trees in six study areas, 1975*

Plot	Area surveyed			Infested trees		Type of infestation		
				Per acre	Per hectare	Mass	Strip	Abandoned
	Acres	*Hectares*	*Percent*	- - - - *-Number-* - - - -		- - - - *-Percent-* - - - -		
Bridger	81	32.8	100	0.04	0.10	67	0	33
Cache	57	23.1	100	.74	1.83	79	0	21
Sawtooth	200	81.0	100	.05	.12	44	12	44
Targhee	5	2.0	3	20.40	50.04	63	26	11
Teton	68	27.5	100	.19	.47	85	0	15
Wasatch	10	4.0	6	1.50	3.71	40	7	53

The attack density was less on abandoned trees than on mass-attacked trees. For example, on the Targhee National Forest, Idaho, attacks averaged 2.5/ft^2 (30.4 cm^2) of bark surface (N = 50; SD = 0.72) on abandoned trees whereas an average of 9.6/ft^2 (30.4 cm^2) (N = 48; SD = 1.6) occurred on mass-attacked trees. The low attack density on abandoned trees suggests it as the reason for abandonment. The beetle attacks many more trees than their numbers are able to mass attack and kill. Most abandoned trees are smaller in diameter ($\overline{X}$= 9.3; SD = 2.3; N = 19) than mass-attacked trees ($\overline{X}$ = 11.4; SD = 2.6; N = 87). Large-diameter trees are more attractive than small ones even when the latter are baited with the beetles' aggregative pheromone (Rasmussen 1972).

Abandoned galleries.--Gallery abandonment was proportionately higher in small than in large diameter trees (fig. 1) as previously noted (Amman 1975). In trees classed as abandoned, females alone were found in 36.7 and 18.7 percent of the galleries for 1975 and 1976, respectively (table 2). Males and females were found together in only 6.7 and 8.3 percent of galleries for the 2 years. Gallery abandonment by females was high, accounting for 51.1 and 62.6 percent of the galleries for 1975 and 1976, respectively. In contrast, beetles found dead in the gallery or pitch tube accounted for only 5.5 and 10.4 percent of the galleries for the 2 years (table 2).

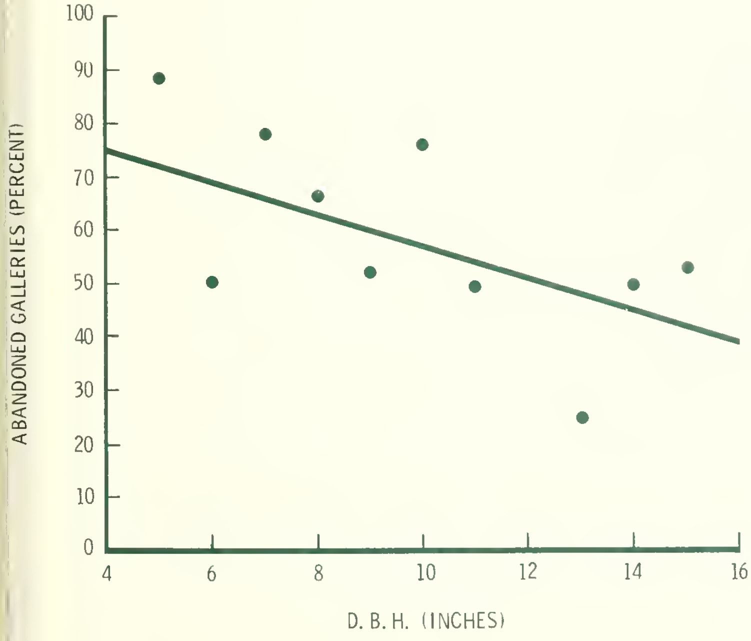

Figure 1.--Proportions of galleries in lodgepole pines of different diameter abandoned by mountain pine beetles.

The proportions of abandoned galleries were inversely related to the proportions of galleries that contained males ($R^2 = 0.44$; $P<0.05$). As the proportions of galleries that contained males increased, the proportions of galleries that contained eggs also tended to increase but was not quite significant ($0.10>P>0.05$). Galleries that contained females only were usually shorter than those containing both male and female (fig. 2), because the male helps to move boring frass and resin (when resin flow is heavy) down and out of the gallery.

Table 2.--*Mountain pine beetle galleries examined and classified according to presence, absence, or death of beetles*

Plot	Galleries examined	Female present	Female and male present	Female dead	Abandoned
	Number	- - - - - - -	- - - - - - -	*Percent* - - - - - -	- - - - - - -
			1975		
Cache	24	41.7	8.3	16.7	33.3
Wasatch	63	31.8	9.5	7.9	50.8
Targhee	57	28.1	1.8	0.0	70.1
Sawtooth	9	100.0	0.0	.0	0.0
Teton	20	40.0	20.0	5.0	35.0
Bridger	7	42.9	.0	.0	57.1
Total in each class	180	*66*	*12*	*10*	*92*
Percent of total galleries	-	36.7	6.7	5.5	51.1
			1976		
Cache	56	17.9	19.6	7.1	55.4
Wasatch	21	19.0	.0	14.3	66.7
Targhee	51	25.5	7.8	15.7	51.0
Teton	65	13.8	.0	7.7	78.5
Total in each class	193	*36*	*16*	*20*	*121*
Percent of total galleries	-	18.7	8.3	10.4	62.6

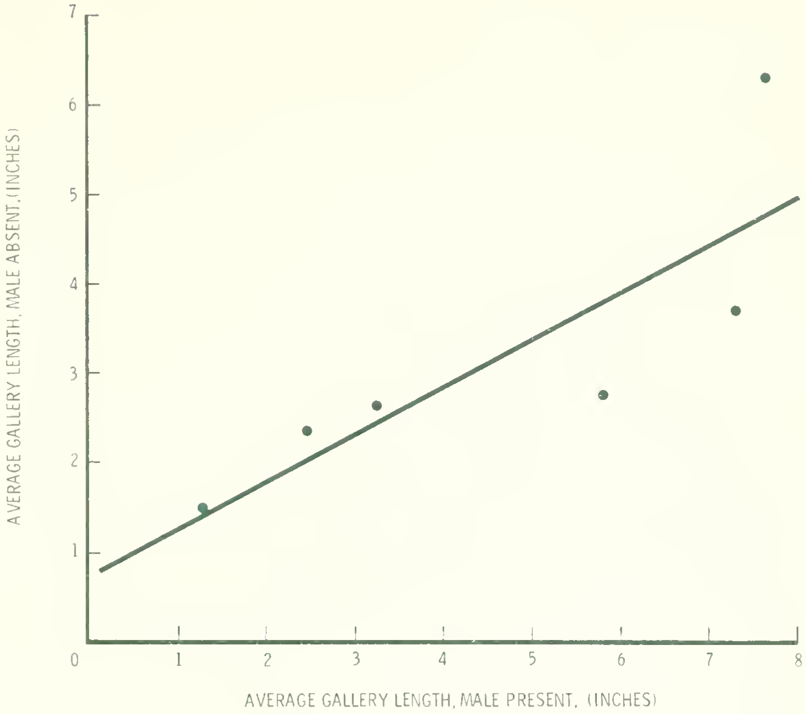

Figure 2.--Average lengths of mountain pine beetle galleries that contained males compared to those that did not contain males (only those plots used that had both categories represented).

Ten females were selected at random and dissected from the total of 20 that had been removed from galleries that showed signs of abandonment. All contained sperm and 6 of the 10 appeared to be of low quality. These females had air bubbles in the abdominal cavity, degenerate ovaries and wing muscles, and only a few visible oocytes. Therefore, lack of female fertilization (Amman 1975) is not a cause of abandonment. The apparent low vigor of some beetles may be one factor for lack of successful gallery establishment and subsequent abandonment. Adults found dead in the galleries or pitch tubes may have been of low vigor.

Successfully established galleries up to 12 inches long ($\bar{X}$= 5.5; SD = 3.4; N = 16) were found adjacent to abandoned or potentially abandoned galleries only 1 to 2 inches long ($\bar{X}$ = 1.9; SD = 0.9; N = 16). Only trees having both types of galleries were used for this comparison. However, no brood matured regardless of gallery length because of resinosus that kills most eggs (Reid and Gates 1970) and prevents development of the few larvae that hatch (Reid and others 1967). Successful gallery construction may be related to the quality and quantity of microorganisms carried by the beetles. Inoculations of blue-stain fungal spores into the tree by the beetle when it starts the gallery and throughout gallery construction causes rapid drying of the wood and bark tissues as the fungi penetrate the sapwood (Reid 1961). Without the fungi, the tissues probably would remain too moist for optimum brood development even in trees that are mass attacked by the beetles. In addition, greater resin flow per attack would occur, particularly at low-attack densities. Therefore, the differences between those females that are able to construct gallery and those that cannot, even though adjacent to each other, may be related to quality and quantity of blue-stain fungi that they carry.

An interesting account of blue-stain quality was given by Rumbold (1941). She wrote, "It was noticed that when there was an epidemic of *Dendroctonus monticolae* (synonymized with *D. ponderosae* by Wood 1963) and *D. ponderosae* in the forest, the specimens sent in, whether insects or the bark or sapwood of infested pines, developed *Ceratastomella montium* and yeast in almost pure form. When the beetle infestation in the forest was light, however, the *C. montium* cultures isolated grew slowly and other fungi also were isolated."

Visually the quality of blue-stain fungi appears to be related to size or vigor of tree infested, for in small trees--particularly those of poor vigor--blue stain development appears poor (Amman 1976). This seems more noticeable toward the latter part of an infestation, after most large-diameter trees have been killed and the beetles are infesting primarily small-diameter trees. Small trees dry excessively, which probably affects blue-stain survival and spore production. Pupal chambers of the beetles in such trees usually do not contain the abundant fungal fruiting bodies found in pupal chambers of the moister large-diameter trees.

The abandoned gallery phenomenon may not be directly associated with the presence or absence of males. The low numbers of males probably are indictive of poor brood conditions such as thin phloem and excessive drying encountered, particularly in small trees (Cole and others 1976). These same conditions also could be expected to adversely affect blue-stain fungal quantity and quality.

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Research Note

USDA FOREST SERVICE INT-285
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507-25th STREET, OGDEN, UTAH 84401

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BIOASSAY OF ALPINE MINE SPOILS FOR PLANT GROWTH AND DEVELOPMENT[1]

Ray W. Brown and Robert S. Johnston[2]

ABSTRACT

*We studied the effects of various soil amendments on the growth and development of two grass species growing in mine spoils. The spoil material came from the McLaren Mine on the Beartooth Plateau in southern Montana and is representative of upper-subalpine and alpine mines present on large areas of the western U.S. The results show that amendments do not have a significant effect on seed germination or plant emergence. Fertilizer and manure applications do, however, significantly increase plant growth and development, and particularly the number of culms and leaves, plant height, leaf area, and shoot and root production per plant. The particular spoils studied were not very acidic, hence, lime treatments were not effective. Two species were studied that appear to have broad adaptability for revegetation of high elevation disturbances; a native, tufted hairgrass (*Deschampsia caespitosa *L.), and an introduced species, Garrison meadow foxtail (*Alopecurus pratensis *L.).*

KEYWORDS: mine spoils bioassay, revegetation, soil amendments, tufted hairgrass (*Deschampsia caespitosa* L.), Garrison meadow foxtail (*Alopecurus pratensis* L.), alpine environments, plant growth and development.

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[1] The research reported here was supported by the USDA Forest Service, Surface Environment and Mining (SEAM) program.

[2] Plant physiologist and research hydrologist, respectively, located at the Forestry Sciences Laboratory, Logan, Utah.

The accelerated rate at which alpine ecosystems are being disturbed in the western U.S. focuses concern on the need to develop applicable revegetation techniques. Unfortunately, only a few studies have documented rehabilitation efforts of alpine disturbances. The limiting environmental factors resulting from disturbance in the alpine zone have been well documented (Billings 1973; Brown and others 1978b; Johnston and others 1975). Also, some of the plant species that appear to be adapted to alpine disturbances have been identified (Brown and others 1978a; Brown and Johnston 1978, 1979; Greller 1974; Harrington 1946; Marr and others 1974; Willard and Marr 1970, 1971) The responses of these plant species in terms of growth and development to specific techniques and soil amendments are, for the most part, still unknown.

Mineral exploration and mining are particularly disruptive in the alpine zone, and often result in the exposure of acid spoil materials that are limiting to plant growth. Other types of disturbance such as recreation, grazing, road construction and others may, however, be more extensive (Brown and others 1978b). These spoil materials typically contain high concentrations of toxic heavy metals and a high proportion of coarse fragments that result in low water-holding capacity and a poor nutrient capital. These limiting edaphic factors appear to be common to mine spoils in the alpine zone throughout the Rocky Mountains, including the states of Montana, Idaho, Utah, Wyoming, and Colorado (Brown and Johnston 1976, 1978; Marr and others 1974). Typical examples include the numerous abandoned mine and exploration sites in this region, such as the McLaren Mine in southern Montana. A considerable amount of research in developing revegetation techniques has been done on this mine because it is representative of acid spoil conditions in western alpine areas (Brown and Johnston 1976, 1978, 1979; Brown and others 1978a, 1978b; Johnston and others 1975; Van Kekerix and others 1979).

In addition to these limiting conditions, alpine areas are characterized by severe climatic environments. Such factors as short growing seasons, cool summer temperatures frequent frost action, high winds, and high solar radiation loads are common (Billings and Mooney 1968; Brown and others 1976; Johnston and others 1975; Willard 1976). These factors, when combined with those conditions typical of mine spoils, greatly restrict the number of adapted plant species capable of completing their entire life cycles on alpine disturbances.

Only a small fraction of the total native alpine flora in the western U.S. appears to be adapted to conditions on disturbed sites (Brown and others 1978a). Of these, however, tufted hairgrass (*Deschampsia caepsitosa* L.) appears to be the single most important native species for alpine revegetation (Brown and Johnston 1978, 1979; Marr and others 1974). In addition, Garrison meadow foxtail (*Alopecurus pratensis* L.) appea to be one of the best adapted introduced species that is commercially available (Brown and others 1978a).

Revegetation research in the alpine zone has stressed the essential role of fertilizer as an amendment (Brown and Johnston 1976). Virtually no documentation is availabl of the role played by other common amendments such as lime and organic matter. Van Kekerix and others (1979) found that the incorporation of peat moss and the use of jute netting significantly improved seedling growth, survival, and water relations of two grass species on the McLaren Mine. In order to extend the rather limited scope of small plot studies that have been done in the past to large scale revegetation of alpine disturbances, quantitative evaluations of such amendments are needed. This is particularly important since so little is known about the growth and development responses of native species to revegetation methods.

This study documents the effects of various soil amendments on plant growth and development in McLaren Mine spoils.

METHODS

Representative spoil material was collected from the McLaren Mine in 1975. The spoil material was sieved through a 0.25 in (0.6 cm) screen to separate out the large rocks. The sieved material was then separated into seven equal fractions to which various amendments were incorporated. Previous field plot research on the McLaren Mine (Brown and Johnston 1976) suggested that certain soil amendments may be beneficial for plant establishment and growth in these spoil materials. A total of seven treatments (or amendments), each replicated four times, were prepared. These included:

1. Control: no amendments added to the spoils material.

2. Fertilizer: a granular 18-24-6 N-P-K ratio fertilizer was incoprorated into the spoil at the equivalent rate to provide 0.005 percent N, or about 100 lb N per acre (111 kg N per ha).

3. Fertilizer-lime: fertilizer was added as in 2 above, plus hydrated lime was incorporated at an equivalent rate of 2,000 lb per acre (2 240 kg per ha), to raise soil pH.

4. Fertilizer-lime-straw: fertilizer and lime amendments were added as described above. Straw was added at an equivalent rate of 5 percent by volume.

5. Fertilizer-straw: fertilizer and straw were added as described above.

6. Fertilizer-lime-manure: fertilizer and lime amendments were added as described above. Manure was added at an equivalent rate of 5 percent by volume.

7. Fertilizer-manure: fertilizer and steer manure were added as described above.

Each of the seven spoil fractions, together with their incorporated amendments, were used to fill four polypropylene containers (for a total of 28 containers). These containers, each with 3 drain holes in the bottom, were 12.75 in long, 10.75 in wide, and 4.5 in deep with a volume of 617 in^3 (32.4 cm X 27.3 cm X 11.4 cm = 10 084 cm^3).

A composite sample of each spoil fraction was collected for soil analyses after the addition of the amendments. Previous experience with these spoils (Brown and Johnston 1976; Johnston and others 1975) had shown that the spoil materials on the McLaren Mine are acid-bearing pyrites containing high concentrations of some heavy metals such as copper and iron. Each of the spoil samples was analyzed for soil texture, saturation percentage, soluable salts, pH, and p/m of P, K, Fe, Cu, and SO_4.

Seeds of tufted hairgrass and Garrison meadow foxtail were planted in equally spaced rows in each container at a depth of 0.25 in (0.6 cm). Three rows of each species were planted, 20 seeds per row, for a total of 60 seeds per species. The sequence of the two species in the rows was randomly selected for each container to reduce bias of plant position in the containers. The seeds were planted at uniform intervals along the long axis of the containers.

The 28 containers were randomly positioned on a greenhouse bench to reduce the effect of environmental gradients. Environmental conditions within the greenhouse were controlled with a day/night temperature range of 72° F ± 5° F day, 60° F ± 3° F night (22° C ± 3° C/16° C ± 1.5° C) with a 12-hour photoperiod supplemented with artificial fluorescent and incandescent lighting. Relative humidity varied from lows of 35 percen during the day to highs of about 75 percent at night. Temperature and relative humidit were recorded with a calibrated Belfort[3] hygrothermograph. Solar flux densities were a recorded, with a Belfort pyroheliograph, and reached peaks of 0.6 cal cm^{-2} min^{-1} at midday.

The containers were watered regularly with a fine-mist spray to reduce surface disturbance due to water drop impact. The soil was maintained at near field capacity throughout the study to avoid any influence due to water stress. Prior to seedling emergence, the surface soil was kept moist on a daily basis, but after emergence wateri frequency was reduced to a schedule that maintained field capacity in the root zone.

After seedling emergence, weekly counts of the number of plants in each row and their total height were recorded. The study was terminated 10 weeks following emergenc when the plants had reached an advanced tillering stage of vegetative development. At this point each of the surviving plants had achieved approximately the same level of development, although not of growth, normally reached after one full growing season under field conditions. Each individual plant of both species from each container was then carefully analyzed for the following characteristics: total number of culms; total number of leaves; plant height; total leaf area; dry weight root production; and dry weight shoot production. Leaf area was determined with a Lambda Area Meter[3] (model LI-3000) using the green tissue prior to drying. The roots were separated from the soil particles by hand using a gentle spray of water and slight agitation. The roots and the shoots were ovendried at 80° C (176° F) for 24 hours, and then were immediately weighed on a top-loading balance to the nearest 0.01 g.

Analysis of variance and Hartley's multiple range test were used to identify significant differences in plant responses due to the amendments (Snedcor 1966).

RESULTS AND DISCUSSION

The results of this study are summarized in figures 1 through 5, and show that the greatest levels of plant growth and development are achieved under the highest levels of soil fertility. Generally, amendments including both fertilizer and manure resulted in the greatest average number of culms and leaves, leaf area, the greatest average plant height, and shoot and root production for both species studied. The average number of plants and the shoot root ratio, however, were not significantly different among treatments.

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

The data means were plotted in bar graph form in figures 1 through 5 to provide a visual evaluation of the effects of each amendment. Figure 1 shows the effect of the various amendments on plant number (emergence and survival) for both species. Analysis of variance results show no significant effect of the amendments; however, the data do reflect the higher germination rates and plant vigor of Garrison meadow foxtail compared to tufted hairgrass.

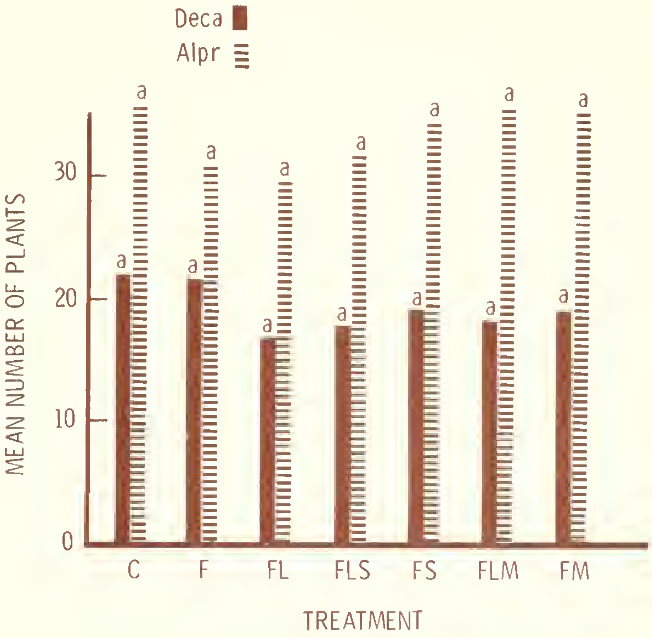

Figure 1.--Mean number of plants of tufted hairgrass (Deca) and Garrison meadow foxtail (Alpr) for each soil amendment. Abbreviations include: C, control; F, fertilizer; L, lime; S, straw; and M, manure. Treatment effects with the same letter do not differ significantly at the 95 percent level. Comparisons are only valid for each species, not between species.

The average number of culms (stems) per plant of both species, as affected by treatment, is illustrated in figure 2. The response of both species shows a strong relationship with increased levels of fertility. The data show that tufted hairgrass produced more culms per plant than Garrison meadow foxtail under all soil amendments. Although differences were statistically significant among the amendments containing lime and straw with fertilizer for both species, the largest increases were achieved when manure and fertilizer were combined.

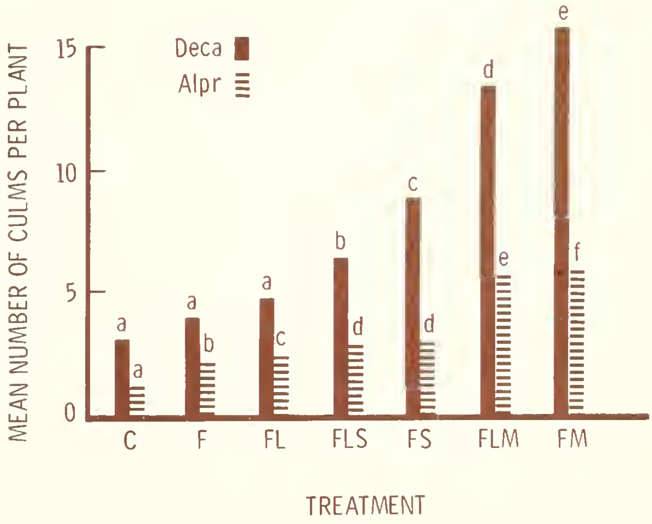

Figure 2.--Mean number of culms per plant of tufted hairgrass (Deca) and Garrison meadow foxtail (Alpr) for each soil amendment. Abbreviations include: C, control; F, fertilizer; L, lime; S, straw; and M, manure. Treatment effects with the same letter do not differ significantly at the 95 percent level. Comparisons are only valid or each species, not between species.

The average number of leaves per plant and the average leaf area per plant are illustrated in figure 3 (A and B, respectively). Both of these parameters reach their highest values under the fertilizer and manure treatments. The strong morphological differences between the two species are reflected by a comparison of number of leaves per plant and average leaf area. Tufted hairgrass has nearly twice as many leaves per plant, but Garrison meadow foxtail has nearly six times the leaf area. Of interest, too, is the effect that the amendments had on the average leaf area per leaf (divide mean leaf area by mean number of leaves); with tufted hairgrass the average area per individual leaf increases by a factor of three times from the control to the fertilizer manure treatment, whereas with Garrison meadow foxtail it increases by a factor of about nine times. This provides some quantative indication of how much enhanced spoil fertility affects plant response.

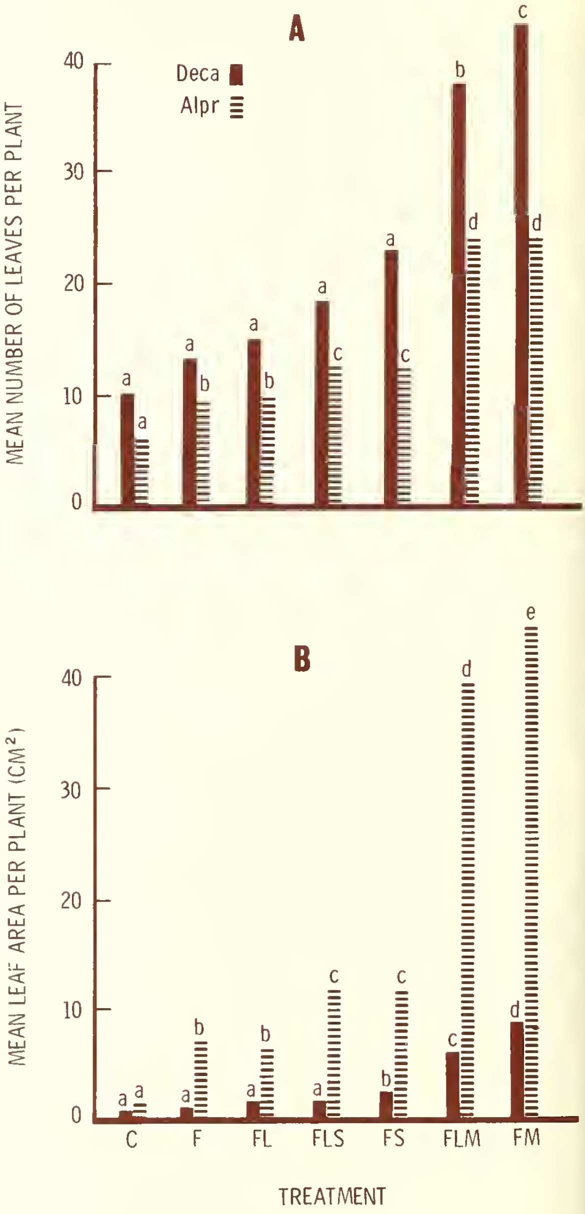

Figure 3.--Mean number of leaves per plant (A) and mean leaf area per plant in cm^2 (B) for tufted hairgrass (Deca) and Garrison meadow foxtail (Alpr) for each soil amendment. Abbreviations include: C, control; F, fertilizer; L, lime; S, straw; and M, manure. Treatment effects with the same letter do not differ significantly at the 95 percent level. Comparisons are only valid for each species, not between species.

Spoil amendments significantly increased plant height of both species (fig. 4). Tufted hairgrass did not respond as dramatically as Garrison meadow foxtail, but this reflects the strong morphological differences between the two species. Generally, tufted hairgrass is a much smaller and shorter plant than Garrison meadow foxtail when grown under similar conditions.

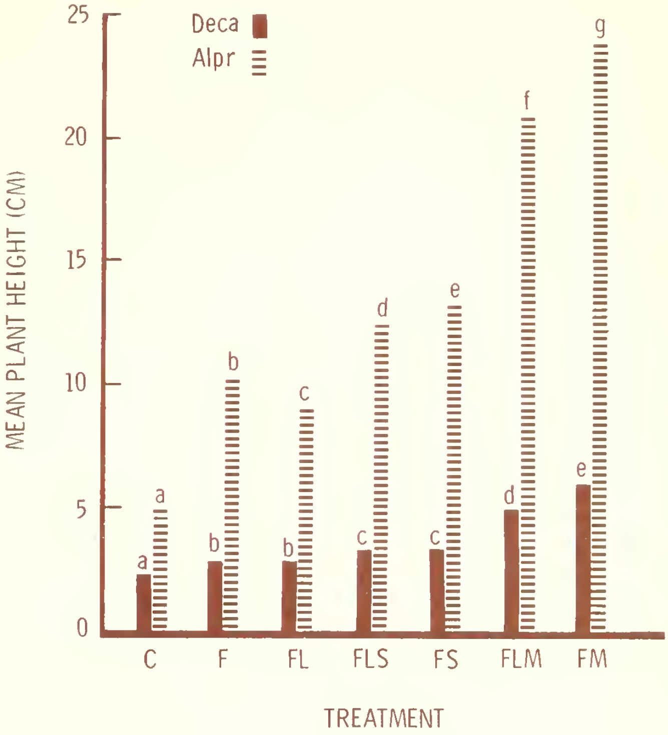

Figure 4.--Mean plant height (cm) of tufted hairgrass (Deca) and Garrison meadow foxtail (Alpr) for each soil amendment. Abbreviations include: C, control; F, fertilizer; L., lime; S, straw; and M, manure. Treatment effects with the same letter do not differ significantly at the 95 percent level. Comparisons are only valid for each species, not between species.

Dry weight production of the shoots and roots, and the shoot-root ratio, as affected by the soil amendments, are illustrated in figure 5 (A, B, and C, respectively). The greatest response of shoot and root production per plant for both species occurred in treatments containing both fertilizer and manure, although lime and straw did enhance production significantly over the control treatment in some cases. Interestingly, however, the shoot-root ratio was not affected significantly by any of the soil amendments, indicating that both shoot and root production of both species responded similarly to the treatments.

The use of lime as an amendment resulted in some unexpected effects. Normally, spoil material from the McLaren Mine is quite acid, with a pH range of 2.0 to 4.5 being quite common. However, the spoil material collected and used in this study had a much higher pH (6.1) than anticipated (table 1). It appears that lime had somewhat of a depressing effect on many of the growth and development variables of both species. For example, the fertilizer-manure amendment resulted in larger, more developed plants than the fertilizer-lime-manure amendment. Similar responses were noted with the fertilizer-lime-straw and fertilizer-lime treatments. Tufted hairgrass is apparently adapted to moderately acid conditions (Brown and Johnston 1976), which suggests that the addition of lime may be detrimental when the pH is already relatively high. The adaptability of Garrison meadow foxtail is not as well known, but the results here indicate that it may have similar characteristics.

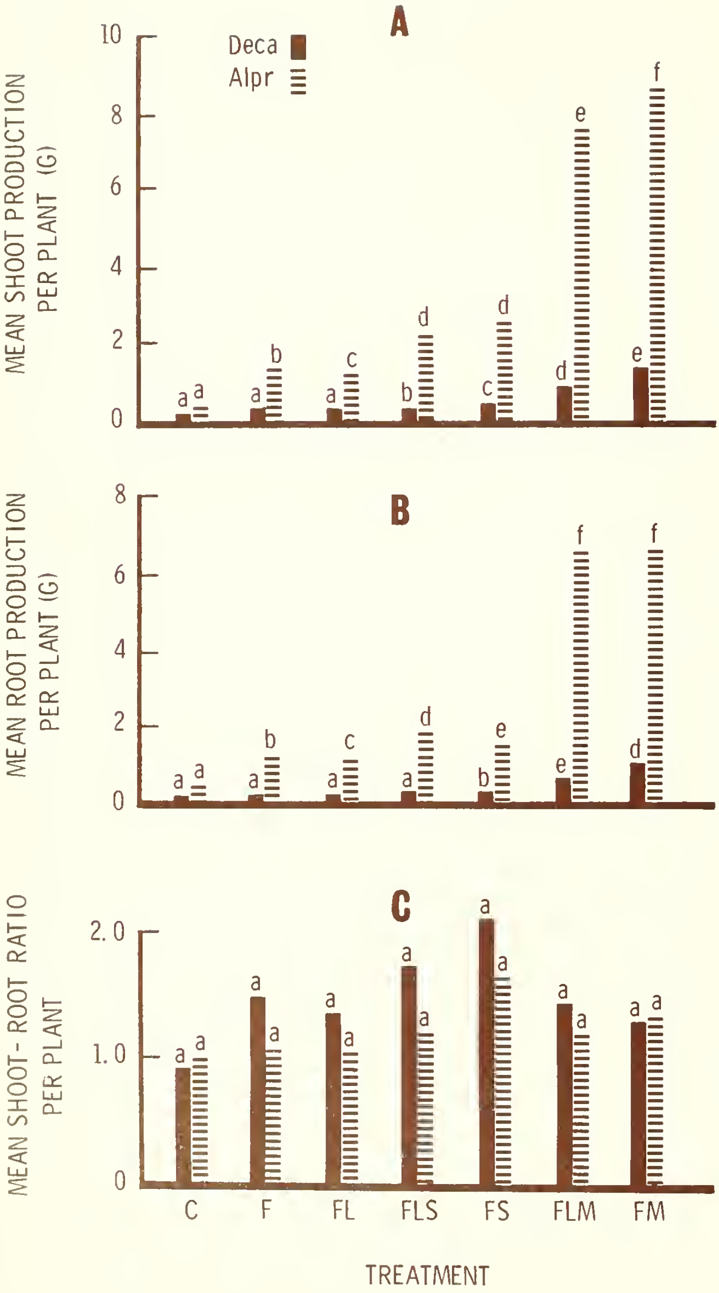

Figure 5.--Mean shoot (A) and root (B) production (dry wt. g) per plant, and mean shoot-root ratio per plant (C) for tufted hairgrass (Deca) and Garrison meadow foxtail (Alpr) for each soil amendment. Abbreviations include: C, control; F, fertilizer; L, lime; S, straw; and M, manure. Treatment effects with the same letter do not differ significantly at the 95 percent level. Comparisons are only valid for each species, no between species.

Table 1.--*Some physical and chemical properties of McLaren Mine spoils and the effect of soil amendments on them*

Soil amendment	Soil texture	Saturation	Soluble salt ECe*	pH	Parts per million				
					P	K	Fe	Cu	SO_4
		Percent							
Control	Sandy-clay loam	41.3	2.8	6.1	3	58	38	29	239
Fertilizer	Loam	42.6	3.2	6.7	5	97	29	20	215
Fertilizer-lime	Sandy-clay loam	41.1	2.8	6.7	5	95	29	24	212
Fertilizer-lime-straw	Sandy-clay loam	43.1	1.9	6.7	4	97	30	24	229
Fertilizer-straw	Sandy-clay loam	42.5	2.8	6.3	3	120	30	23	233
Fertilizer-lime-manure	Loam	44.7	3.6	6.9	7	430	26	22	246
Fertilizer-manure	Sandy-clay loam	42.1	4.4	6.6	10	490	33	12	234

* Electrical conductivity, mmhos per cm.

Straw, incorporated as an organic amendment into the spoil, generally resulted in greater levels of growth and development than the control or fertilizer treatments. It was not, however, as effective as manure, presumably because of its low nutrient value and because it may have tended to tie up available soil nitrogen. Straw is probably an effective organic constituent in some cases, but in this study it did not appear to impart any favorable characteristics to the spoil material in terms of increased saturation percentage, pH, or other soil factors (table 1). The role of straw in revegetation of alpine disturbances is probably more important as a surface mulch to retard evaporation and to reduce the incidence of frost action in the soil. Methods and rates of application of these various amendments are discussed by Brown and Johnston (1978, 1979), and by Brown and others (1978a).

The soil data in table 1 suggest that only fertilizer and manure appreciably affected the soil characteristics examined compared to those in the control treatment. The availability of P and K appear to have been increased substantially by the manure and fertilizer amendments. Lime apparently caused an increase in pH, but this may not have been significant. The soil amendments did not appear to significantly affect any of the other spoil characteristics sufficiently to affect plant growth.

Interpretation of these data must be tempered with caution. For example, the data suggest that Garrison meadow foxtail, by virtue of its much higher production and growth, would be more desirable for revegetation than tufted hairgrass. What the data do not illustrate, however, is the overall adaptability to high elevation site conditions. Research and field observations clearly document the broad adaptability of tufted hairgrass to alpine disturbances and the relatively poorer long-term performance of Garrison meadow foxtail (Brown and Johnston 1976; Brown and others 1976; Marr and others 1974). Bioassay studies, such as reported here, are only capable of evaluating plant responses to edaphic factors, but they are not designed, nor are they intended, to evaluate interactions with other limiting factors such as climatic variables. Environmental conditions in the field are infinitely more complex than those reproduced in this greenhouse study. Consequently, comparisons between these data and actual field trials may be somewhat different.

CONCLUSIONS

Increasing fertility of the raw spoil material significantly improved plant growth and development of both tufted hairgrass and Garrison meadow foxtail. The results of this study, together with field data collected in previous research (Brown and Johnston 1976, 1978; Brown and others 1976, 1978a), showed that when fertilizer and manure are incorporated into the spoil material plant growth and development can be substantially improved. Because both fertilizer and manure are readily available commercially, and because of the obvious improvement of plant growth and development resulting from them, it is recommended that both be included in revegetation efforts in alpine areas. Although soil analyses should be made prior to revegetation, it is apparent from this study, as well as many others, that fertility is one of the most important limiting factors affecting the successful establishment of a self-sustaining plant cover.

The use of lime and straw amendments should be based on local site conditions. Lime should only be used when spoil pH is lower than 5.5 (e.g., under acid conditions where the solubility of heavy metals is toxic for plant growth and when essential nutrients are unavailable). Application rates will vary with spoil characteristics and should be determined by spoil analysis. Straw is most useful as a surface mulch, especially when tacked down with either netting or one of the various chemicals commercially available for this purpose. Straw incorporated into the spoil is probably not as effective as manure because it tends to reduce the available nitrogen in the soil by increasing the carbon-nitrogen ratio.

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Research Note

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ROUNDWOOD PRODUCT POTENTIAL IN LOGGING RESIDUE

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Thomas R. Bohannan[1]

ABSTRACT

Logging residue in a small clearcut of mixed Douglas-fir and ponderosa pine was examined to determine if commercial products other than fuel could be salvaged prior to disposal by burning. About 112 stud logs, 195 fenceposts, and 41 fence rails valued at $534 could be salvaged from each acre. Products would be slightly lower in quality and more time consuming to salvage than to harvest by conventional means.

KEYWORDS: Postharvest residue, wood products, salvage

Forest land managers have long been concerned with the quantity and quality of the wood left on an area following the removal of the sawlogs. This residue, consisting of small unmerchantable trees, tree tops and branches, and dead, rotten, or cull trees is usually disposed of by burning, a time-consuming and costly process. Ideally, the residues would be utilized; however, uncertainty about salvable products and cost of removal have deterred the harvesting of residue.

Several field sampling and photo systems have been devised and used to estimate the quantity of post-harvest residue (Dell and Ward 1971; Maxwell and Ward 1976a, 1976b). Although the systems provide an estimate of the residue volume either in tons or cubic feet per acre, they do not evaluate the suitability of individual pieces for specific products.

As a part of a silvicultural-harvesting study, the roundwood product potential of the logging residue on a small clearcut area was determined. This research note reports the number and value of stud logs, fenceposts, and fence rails that could be recovered from the residue of a harvested mixed Douglas-fir-ponderosa pine (*Pseudotsuga menziesii-Pinus ponderosa*) stand.

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[1] Wood Technologist and Forestry Technician, respectively, located at the Intermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

STUDY PROCEDURE

The study area was located on the University of Montana's Lubrecht Experimental Forest about 30 miles northeast of Missoula, Mont. The terrain was gently rolling, with slopes less than 10 percent and an aspect of west to northwest. The mature trees were Douglas-fir and ponderosa pine, and the understory had some western larch (*Larix occidentalis*) as well as the overstory species. The principal investigation on this area was concerned with the evaluation of environmental and economic consequences of different silvicultural cutting prescriptions and residue disposal alternatives.

A 4.95-acre (2.0 ha) clearcut that had been tractor skidded was selected for study Prior to harvesting, the area had been cruised and the number and volume of the trees, by species and diameter, were estimated. During harvesting, all trees, regardless of size, were felled and no attempt was made to pile or rearrange the residue after the log skidding had been completed. At this time, too, a complete record was obtained of the diameters and lengths of all the logs removed from the area.

Following the completion of the fall harvesting, a complete inventory was made of the potential products obtainable from the postharvest residue. A two-man crew, an estimator and a recorder, was used to obtain the data. This crew made repeated traverses back and forth across the area, measuring and identifying the pieces as either stud logs, fenceposts, or rails. The counted pieces as well as all the other material within the traversed area were marked with paint using a tree-marking gun.

Criteria for different products were as follows:

1. Stud logs - minimum diameter at small log end 5.5 inches (14 cm); minimum length 8 feet (2.4 m); at least 50 percent sound.

2. Fenceposts - minimum diameter at small end of piece 2.5 inches (6 cm); minimum length 6.5 feet (2 m); no decay or rot permitted.

3. Fence rails - minimum diameter at small end of piece 2 inches (5 cm); minimum length 10 feet (3 m); no decay or rot permitted.

An average value was assigned to each product category and a total value for the potential products determined.

RESULTS AND DISCUSSION

Results of the preharvest tree inventory are shown in table 1. Only two species, Douglas-fir and ponderosa pine, were represented in the cruised sample of merchantable trees. The same two species and western larch made up the unmerchantable sample. The preharvest volume of trees 5 inches (12.7 cm) or larger in diameter breast height are shown in table 2. Volume (per acre) of Douglas-fir was 2,601 cubic feet (182.0 m^3/ha) and of ponderosa pine 232 cubic feet (16.2 m^3/ha). The estimated total volume to be harvested was 14,023 cubic feet (981.2 m^3/ha).

Table 1.--*Distribution of trees per acre (per ha) by species and d.b.h. on an area to be clearcut*

Diameter (d.b.h.)		Tree species			Total trees
		Douglas-fir	Ponderosa pine	Western larch	
Inches	*Centimeters*	- - - - - - - - - -*No. trees per acre*- - - - - - -			
<0.9	<2.3	2,492	-	23	2,515
1.0-2.9	2.5-7.4	323	46	-	369
3.0-4.9	7.6-12.4	230	-	-	230
Subtotal		3,045	46	23	3,114
		(7,521)	(114)	(57)	(7,692)
5.0-6.9	12.7-17.5	-	-	-	-
7.0-8.9	17.8-22.6	56	-	-	56
9.0-10.9	22.9-27.7	15	11	-	26
11.0-12.9	27.9-32.8	-	4	-	4
13.0-14.9	33.0-37.9	13	3	-	16
15.0-16.9	38.1-42.9	14	-	-	14
17.0-18.9	43.2-48.0	14	-	-	14
19.0-20.9	48.3-53.1	3	-	-	3
Subtotal		115	18	-	133
		(284)	(44)	-	(328)
Grand total		3,160	64	23	3,247
		(7,805)	(158)	(57)	(8,020)

Table 2.--*Preharvest volume of trees 5 inches (12.7 cm) and larger in diameter by species and diameter class*

Diameter class		Douglas-fir		Ponderosa pine		Total volume	
Inches	*Centimeters*	*Ft^3/acre*	*Ft^3/area*	*Ft^3/acre*	*Ft^3/area*	*Ft^3/acre*	*Ft^3/area*
5.0-8.9	12.7-22.6	298	1,475	-	-	298	1,475
9.0-14.9	22.9-37.9	532	2,633	232	1,148	764	3,782
15.0+	38.1+	1,771	8,766	-	-	1,771	8,766
Total		2,601	12,874	232	1,148	2,833	14,023
		(182 m^3/ha)		(16 m^3/ha)		(198 m^3/ha)	

The record of material removed from the area showed that an average of 3,567 cubic feet (101.9 m^3) was taken from each acre and a total of 17,657 cubic feet (499.7 m^3) was removed from the area. These volumes, per acre and total, exceeded the preharvest estimates. The sampling system and the use of inexperienced cruising personnel are possible reasons for this data discrepancy. Also, the cruise estimate was based on diameter breast high, whereas the volume removed was determined from outside bark measurements on log ends.

The postharvest inventory of the potential products left on the study is as follows:

Product	Per acre	Total area
Stud logs	112	552
Posts	195	963
Rails	41	201

The data in the above tabulation must be considered as the greatest possible number of potential products with complete disregard for the species, quality, and production economics. Although the species in this stand are frequently used for stud logs, rarely are they used for posts and fence rails. The quality of many of these products would be inferior to that of products obtained from smaller trees. Stud logs and posts cut from tree tops would have more knots, more taper, and would cost more to produce than these same products made from the clear stems of smaller trees.

Based on early 1979 market conditions, average delivered mill values were determine for the different products. Products and values were:

Product	Value
Stud logs, M bd.ft.	$160.00
Post, each	.40
Fence rails, each	.25

Assuming 20 logs per cord and two cords per M board feet, the value of the stud logs was $2,208.00. The value of the posts was $385.20 and the rails $50.25. The total value of all products from the area's postlogging residue was then $2,643.45 or $534 per acre. In addition, some fuel wood could be obtained from the defective pieces of wood not suitable for products. These approximations indicate that the potential products obtained from the postharvest residue possess considerable value. The time and cost of producing these products are probably the principal deterrents to their utilization.

SUMMARY AND CONCLUSIONS

An inventory of stud logs, fenceposts, and fence rails on a clearcut area in a mixed Douglas-fir ponderosa pine stand indicated that a considerable number of these products might be obtained from the postharvest residue. A total of 552 stud logs, 963 fenceposts, and 201 fence rails were identified on the 4.95 acre (2 ha) area. Under current market conditions (early 1979) these products have an approximate total value of $2,643.45 or $534 per acre.

The time and cost of salvaging these products from the residue are the probable reasons more of these products are not utilized. In addition, the products are usually of lower quality than the same products made from smaller trees.

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USDA FOREST SERVICE INT-287
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March 1980

ESTIMATING SURVIVAL AND SALVAGE POTENTIAL OF FIRE-SCARRED DOUGLAS-FIR

Collin D. Bevins[1]

ABSTRACT

*A dichotomous event regression model is used to estimate survival of fire-injured interior Douglas-fir (*Pseudotsuga menziesii *var.* glauca*) 1 year after burning. A preliminary salvage marking guide is presented based upon stem diameter at breast height and crown scorch height.*

KEYWORDS: Douglas-fir, crown scorch, postfire mortality, timber salvage

Tree mortality following fire has been of concern to timber managers since the mid-1920's. This concern has historically centered around the identification and salvage of trees most likely to die as a result of fire damage or subsequent insect or disease infestation. The objectives of a salvage timber sale following fire are to recover the value of dead and dying trees and to protect survivors from insect attack.

Most investigators have related percentage of tree mortality during the first year or two after fire to one or more indicators such as fire intensity, crown scorch, cambium damage, stem diameter, bark char height, degree of needle consumption, presence or absence of bark beetles, and season of the year during which the fire occurred. Postfire tree mortality research began in the ponderosa pine (*Pinus ponderosa* Laws.) region of the southwest and dealt mainly with increased susceptibility of fire-damaged pines to western bark beetle (*Dendroctonus* spp.) attack (Miller and Patterson 1927; Salman 1934; Connaughton 1936; Herman 1954; and Wagener 1955). Herman (1950) was the first to relate postfire tree mortality to fire intensity and tree size and used the two factors in a "rule of thumb" salvage marking guide. Lynch (1959) used percentage of live crown scorched and stem diameter as the best indicators of ponderosa pine mortality in northeast Washington.

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Similar studies have been performed more recently in the loblolly (*Pinus taeda* L.) slash (*Pinus elliottii* Engelm.), longleaf (*Pinus palustris* Mill.), and shortleaf (*Pinus echinata* Mill.) pine region of the southeast (McCulley 1950; Ferguson 1955; Storey and Merkel 1960; Mann and Gunter 1960; and Martin 1965), and in the red pine (*Pinus resinos* Ait.) and eastern white pine (*Pinus strobus* L.) areas of the north and midwest (VanWagn 1963; Sucoff and Allison 1968; and Methven 1971). The studies again related stand average fire-induced tree mortality to stem size, degree of crown damage, cambium injur, season of the fire, and insect attack.

Few studies to date have dealt directly with fire-induced mortality of interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Connaughton (1936) reported 82 percen Douglas-fir mortality 2 years after a 45,000-acre wildfire in Idaho. Furniss (1965) examined extent of injury to Douglas-fir crowns and cambium and its effect on the incidence and severity of attack by the Douglas-fir bark beetle; however, he did not report on tree mortality as a result of either fire damage or insect attack.

The present study is an attempt to relate survival of interior Douglas-fir 1 year following fire to various easily assessable indicators. This study is restricted to mortality resulting from fire injury only, and not as a result of subsequent insect or disease infestation.

FIELD METHODS

Nineteen plots within a western larch/Douglas-fir (*Larix occidentalis* Nutt./*Pseudotsuga menziesii* var. *glauca*) stand in west-central Montana were burned throughout the 1973 fire season to determine the characteristics and effects of understory burning on the stand.[2] Plots were burned on a variety of sites with different fuel loads, fuel moistures, and weather conditions. Douglas-fir stem diameters, tree heights, and live crown heights were recorded for 176 trees within the burned plots. Only trees of 5-inch d.b.h. (12.7 cm) or greater were tallied. The crown scorch height of each tree was recorded to the nearest foot a few weeks following burning.

Trees were inspected following emergence from dormancy in the spring of 1974 to determine first year postfire survival. An increment borer was used to remove four cambium samples at breast height from each tree. Cambium cores were sampled from the upslope, downslope, and two cross-slope faces of each stem. The cores were treated with a 1 percent solution of Orthotolidine[3] followed by a 3 percent solution of hydroge perioxide as described by Hare (1965). This treatment turns living cambium blue while dead tissues remain uncolored. Trees were considered dead if three or more of the samp cores contained dead cambial tissue.

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[2] Norum, Rodney A. 1975. Characteristics and effects of understory fires in western larch/Douglas-fir stands. Unpubl. Ph.D. diss. School of For., Univ. Mont., Missoula, Mont. 155 p.

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

ANALYTICAL METHODS

Previous studies have expressed postfire tree mortality as the percentage of stems killed within a tree size or fire damage class. The assumption was that all trees within the class had similar survival probabilities represented by the class's mean percentage of survival. In fact, individual tree survival at any point in time following fire is a dichotomous event; either the tree is alive or it is dead. A model representing a continuous dichotomous event rather that a class mean percentage of survival permits the characteristics of, and damage sustained by, each tree to be used in estimating the individual's survival probability. Rather than assign each tree to a group based upon some tree stem or fire damage criteria and compute a group survival, a regression equation was used to predict the dicotomous outcome (1 = live, 0 = dead) for each tree 1 year following fire based upon a set of predictor variables.

A dichotomous event regression routine, RISK (Hamilton 1974), was used to obtain tree survival predictions within the probability interval (0,1). The routine fits the data to a logistic function form:

$$p = (1 + e^{(a + b'x)})^{-1} \text{ , where}$$

P = event outcome probability in the interval (0,1),

e = base of the natural logarithms,

a = regression constant,

b'= transpose of the vector of regression coefficients, and

x = vector of independent variables.

Potential survival indicators were restricted to those factors that could be easily measured or estimated in the field without any knowledge of prefire stand conditions or behavior of the fire. Candidate survival indictors examined were stem diameter at breast height, crown scorch height, and percentage of live crown scorched. The indicators were tested alone and in combination to select a model which best fit the data. Goodness-of-fit was tested using the chi-square statistic as incorporated into the RISK routine and recommended by Hamilton (1974). The chi-square evaluates the deviation of the model predictions from the data to be fitted over the range of predictions (0,1). If the chi-square is significantly large for the chosen confidence level, the model does not adequately fit the test data.

The RISK program also computes Student's t statistics for each regression coefficient in the model to determine whether they are significantly different from zero, and an analysis of variance F ratio to test the significance in the amount of variation in the data explained by the model.

RESULTS

Seventy-five of the 176 Douglas-fir (43 percent) were dead 1 year following fire. Surviving trees tended to be taller and have greater stem diameters than those that died (table 1). Surviving trees also had lower scorch heights and percentage of live crown scorched than the dead trees.

Table 1.--*Characteristics of live and dead fire-injured Douglas-fir 1 year following fire*

Cambial condition	Number	Stem d.b.h.			Tree height			Scorch height			Crown scorch		
		Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
		- - -	*Inches*	- - -	- - -	*Feet*	- - -	- - -	*Feet*	- - -	- -	*Percent*	- -
Dead	75	5.0	7.3	15.0	25.0	45.5	80.0	0.0	27.1	70.0	0	31	100
Live	101	5.0	8.9	18.9	25.0	49.0	80.0	0.0	16.4	57.0	0	10	73
Total	176	5.0	8.2	18.9	25.0	47.5	80.0	0.0	20.9	70.0	0	19	100

The combined use of stem d.b.h. and crown scorch height as independent variables in the dichotomous event regression represented the outcomes (death or survival) more closely than any other combination of predictor variables. The chi-square goodness-of-fit statistic was not significant at $p = 0.995$ indicating good agreement between regression predictions and field observations. The derived survival probability equation is:

$$P = \left(1 + e^{(0.1688 - 0.3174 X_1 + 0.09321 X_2)} \right)^{-1}, \text{ where}$$

P = survival probability,

X_1 = stem diameter at breast height (inches), and

X_2 = crown scorch height (feet).

The analysis of variance F ratio for the relationship is highly significant ($p < 0.005$), and the regression coefficients' Student's t statistics are also highly significant ($p < 0.005$) for stem d.b.h. and crown scorch height. The regression constant was not significantly different from zero.

The relationship between Douglas-fir postfire survival and crown scorch height is represented graphically in figure 1 for several stem diameters.

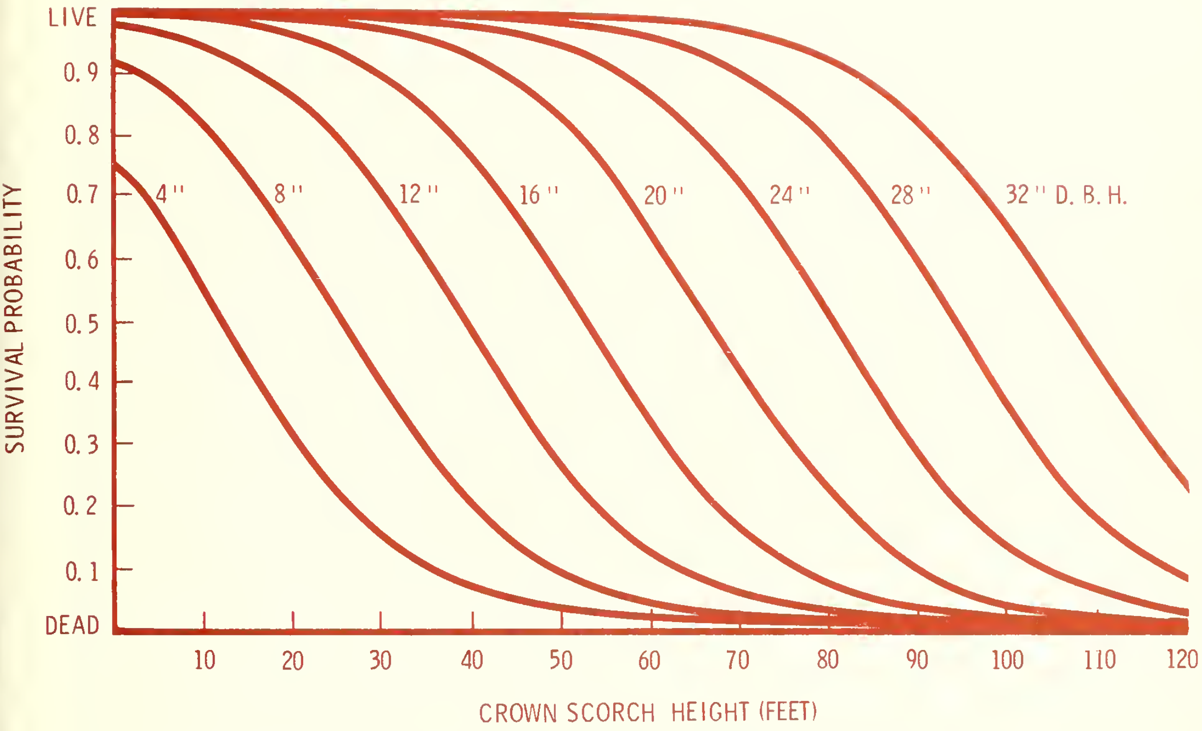

Figure 1.--Interior Douglas-fir postfire survival probability as a function of stem diameter at breast height and crown scorch height.

DISCUSSION

Several investigators have demonstrated relationships between stem d.b.h. and postfire tree survival (McCulley 1950; Mitchell 1954; Ferguson 1955; Lynch 1959; Storey and Merkel 1960). Larger stemmed conifers tend to have thicker barks, which insulate the cambial tissues and increase the tree's ability to withstand high heat fluxes.

Percentage of the live crown length scorched by the fire has also been a useful indicator of fire-induced tree mortality (Herman 1954; Ferguson 1955; Lynch 1959; Mann and Gunter 1960; VanWagner 1963; Sucoff and Allison 1968; Methven 1971). Crown scorch height is a function of the fireline intensity (VanWagner 1972).

The Douglas-fir postfire survival probability equation therefore contains two variables that are independent of each other and account for the two most important components determining survival: the amount of heat applied to the tree (as manifested by the crown scorch height) and the ability of the tree to withstand the applied heat flux (as indicated by the stem d.b.h.).

A preliminary guide for marking salvable interior Douglas-fir was developed from the survival probability equation. Figure 2 presents the relationship in a form suitable for field use. The survival probability of an individual Douglas-fir stem 1 year following fire is found at the intersection of the tree's d.b.h. (x axis) and the observed crown scorch height (y axis). For example, a 20-inch (51 cm) d.b.h. Douglas-fir with a 20-foot (610 cm) crown scorch height has a survival probability of 90 to 99 percent. The same tree with a 75-foot (2 286 cm) scorch height has only a 10 to 50 percent chance of survival.

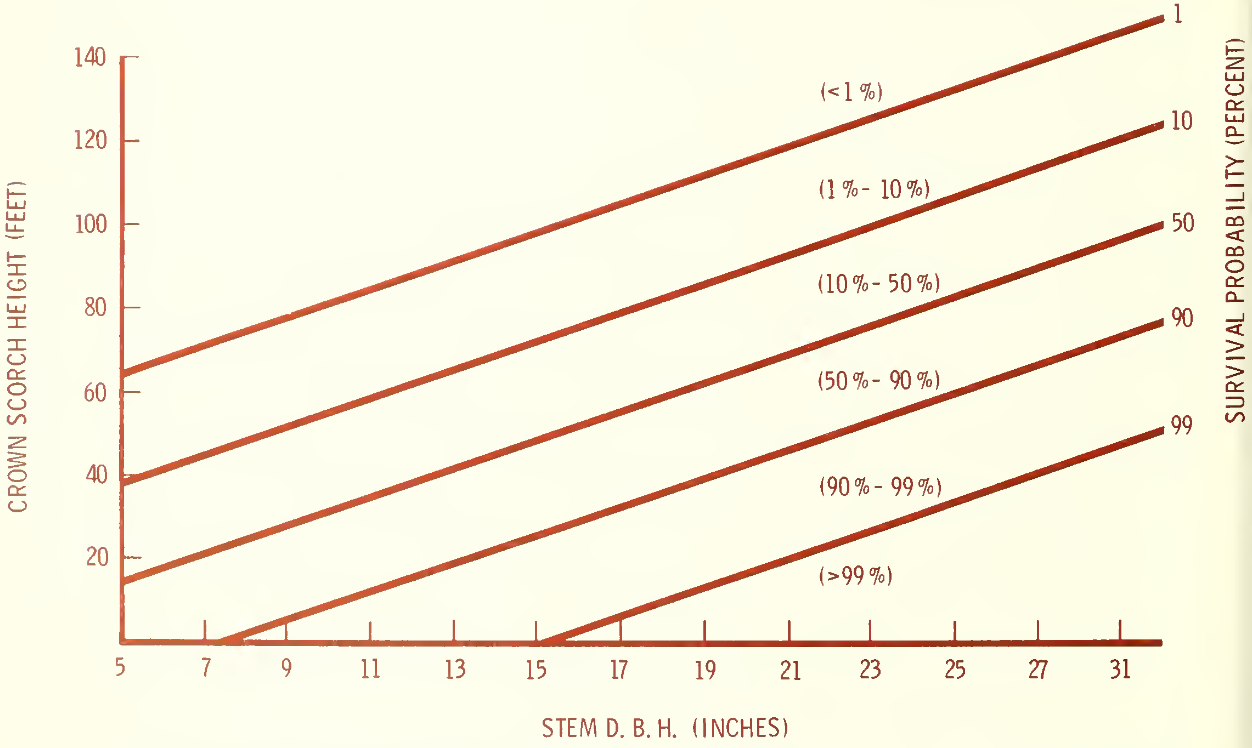

Figure 2.--A preliminary salvage marking guide for fire-injured interior Douglas-fir. Individual tree survival probability is determined from stem d.b.h. (x axis) and observed crown scorch height. Survival probability is indicated on the dark lines, and ranges indicated within brackets between the lines.

The guide should be considered a trial procedure due to several limitations in its development. First, the survival probability was based upon a limited sample of 176 interior Douglas-fir with stem diameters in the 5- to 19-inch (12.7 to 48.3 cm) range. Second, trees were inspected only the first year after burning, and data are not available on survival past the first year. Third, no information is available on the incidence of subsequent insect attack and its effect on Douglas-fir survival.

Finally, the test plots were fired using understory burning techniques, resulting in low to moderate fire intensities. The restricted range of fire intensities should not adversely affect the performance of the guide since higher fire intensities (with higher scorch heights) would only have made the "live or dead" outcome more certain. In fact, the proposed guide may be usefully applied in the determination of acceptable scorch heights in Douglas-fir stands requiring understory burning precisely because it was developed from low-intensity fire treatments.

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March 1980

COLD HARDINESS OF WESTERN LARCH POPULATIONS

G. E. Rehfeldt[1]

ABSTRACT

Cold hardiness of 1-year old seedlings representing 78 populations of Larix occidentalis *was studied. No differences could be detected among populations in tolerance to cold before frost in early September.*

KEYWORDS: Cold hardiness, cold acclimation, ecological genetics

Levels of cold tolerance differentiate populations of numerous forest trees: *Liquidambar styraciflua* (Williams and McMillan 1971), *Quercus rubra* (Flint 1972), *Abies grandis* (Larsen 1978b), and *Pseudotsuga menziesii* (Larsen 1978a; Campbell and Sorensen 1973; Rehfeldt 1977, 1978). In fact, populations of *Pseudotsuga menziesii* are so well differentiated that variation in hardiness has been used to limit seed transfer for reforestation in northern Idaho (Rehfeldt 1979a,b) and western Montana (Rehfeldt 1980).

Objectives of the present research on western larch (*Larix occidentalis*) involved assessing variation in cold hardiness among populations and developing limits of seed transfer from patterns of variation.

MATERIALS AND METHODS

About 50 seedlings representing each of 78 populations of western larch were grown in plastic containers (150 cm^3) in a shadehouse at Moscow, Idaho. Populations represented the geographic and ecologic distribution of the species in Montana, Idaho, and northeast Washington. Each population was characterized by latitude, longitude, elevation, and habitat type.

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

Long shoots were exposed to freezing treatments early in September of the first growing season. Freezing tests were conducted on a single date because differentiatio of populations of *Pseudotsuga menziesii* were most pronounced after bud set but before frost (Rehfeldt 1979b), and because a single sampling date required a minimum number of seedlings.

Freezing tests were conducted according to the general procedures outlined by Levitt (1972). For each population, six sets of 10 shoots were cut, moistened, and packaged in plastic bags. Plastic bags were suspended in a freezing chamber equipped with two fans for providing circulation. One set of bags from each population was frozen at a rate of 5°C/h to one of six test temperatures between -11°C and -16°C. Shoots were removed from the freezer when remote temperature sensors indicated that internal air temperatures had reached desired levels. Shoots were thawed at 2°C for 24 h, and afterwards, plastic bags were placed on a shaded greenhouse bench for 2 days. The proportion of shoots injured by freezing was recorded for each population at all test temperatures. Injury was scored by discoloration of wood tissues.

An analysis of variance was used to determine the extent of population differentiation. Regression techniques were used to relate patterns of differentiation to geographic and ecologic conditions of the seed sources.

RESULTS AND DISCUSSION

Whereas 88 percent of the shoots subjected to -16°C exhibited injury, only 15 percent were injured at -11°C. Damage to populations ranged from 18 to 87 percent. Yet, as shown by the following analysis of variance, differences among populations could not be detected statistically:

Source of variance	Degrees of freedom	Mean square	F-value
Treatments	5	50,268	54.39**
Populations	77	1,132	1.23
T x P	385	924	

**Statistical significance at the 1 percent level of probability.

The failure of statistical analyses to detect differences among populations is attributed to large effects of the interaction of populations with temperature treatme Interaction was apparent in the original data: differences among populations simply were not consistent between temperature treatments.

Attempts were made to correlate population mean values with geographic and ecologic variables of the seed source: latitude, longitude, elevation, and habitat type. Simple correlations of the percent injury with the first three variables and regression analyses of injury on habitat types yielded only one statistically signific association. A weak positive correlation (r = 0.30, significant at the 1 percent level of probability) was observed between percent injury and latitude of the seed source. Because no other variables were related to mean injury, multivariate analyses were senseless.

The results imply that populations of western larch are not differentiated according to cold tolerance at a time when first frosts of autumn can be expected. But, the failure to detect differences could also result from experimental errors. Therefore, tests of cold hardiness in western larch should be repeated to either verify or refute present results.

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MEASURING ANNUAL GROWTH RINGS USING AN ELECTRONIC MEASURING MACHINE

Russell T. Graham[1]

ABSTRACT

Measurement of tree diameter growth is important in most forestry research. The electronic Addo-X system for measuring annual growth rings is described. The measurements, accurate to 0.01 mm, are recorded on printed tape and punched cards. The problems, time, and costs of measuring increment cores and tree cross sections are discussed.

KEYWORDS: Increment cores, measurement, growth, equipment

Measuring of tree diameter growth, important in most forestry research, may be accomplished by a variety of methods. Repeated diameter measurements on tagged trees was one of the first methods used. This procedure involves following individual trees over time, remeasuring each tree at 5- to 10-year intervals. Increment cores, used in assessing diameter increment, are easy to collect and use. Cross sections, also used in tree growth studies, generally are more difficult to transport, store, prepare and measure than increment cores.

A forest growth experiment may require many samples consisting of increment cores or cross sections. It is time consuming to measure accurately the width of each annual ring in cores or cross sections from thousands of trees, using a hand-operated measuring device. Also, hand recording the reading from a measuring device onto data forms may result in many errors. Additional errors may occur during transcription from the forms to punched cards or tapes. Much time and effort may be spent in finding and correcting errors.

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Several different pieces of equipment have been developed and used to measure increment cores. They range in sophistication from a modified ruler to electronic and mechanical systems. In 1939, the development of the Bannister incremental measuring machine was started.[2] It is a hand-operated machine, but through an interface system it may be connected with automatic data processing equipment. With electronic measuri systems becoming more sophisticated, the Addo-X[3] electronic annual growth ring measuri machine was developed. It is a power driven machine that is capable of automatically recording the increment measurements onto punched cards or tape.

THE ADDO-X SYSTEM

The Addo-X system is an electronic system developed to measure the width of annua growth rings on increment cores or cross sections. It makes the measurement of the samples easy, efficient, and accurate. The system contains three components: a measuring unit, a mechanical adding machine, and an IBM 029 keypunch.

The measuring unit does the actual measuring of the samples. The samples are measured by viewing the annual rings through a 20 or 40 power microscope with a cross hair. The increment cores or cross sections are held in special holders while being measured and are moved under the microcsope by a motor-driven mechanical stage. To facilitate rapid sample measurements, the stage may be moved at various speeds, which are controlled by light hitting a photo resistor. The more light hitting the photo resistor, the faster the stage moves; the less light hitting the photo resistor, the slower the stage moves. A manual fine adjustment is provided for accurately placi the cross hairs on the beginning and end of each annual increment. An electronic count in the measuring unit is controlled by the same light source as the speed control. If the light source fails, the carriage will not move. To insure measurement accuracy, the angle at which the cores move under the microscope may be adjusted. This enables each core or cross section that is being measured to be turned so that the vertical cross hair is perpendicular to the radius or core. From the electronic counter, the measurement is sent to an indicator box that visually shows the width of each annual ring and the total number of rings measured.

The second part of this system is a mechanical adding machine with electronic input. It receives the measurements from the measuring unit and records the subtotal of the measurements or subtracts the measurement from the total previous measurements.

The third part of the system is a modified 029 IBM keypunch, with two drums to control the spacing and locating of data on each keypunch card. The keypunch receives the information from the adding machine via an electronic interface. The data may be arranged on the keypunch card in almost any manner desired.

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[2] Fred C. Henson Co., 27402 Camino Capistrano, Laguna, California 92677.

[3] Technicon Systems Service, 304 East Alameda Avenue, Burbank, California 95102. Approximate price, 1977, $25,000.

Measuring Capabilities

The Addo-X system has many options for recording annual ring measurements. Ring widths may be measured in 0.01 mm intervals up to a maximum ring width of 9.99 mm. Ring widths also can be measured in 0.1 mm intervals up to a maximum ring width of 99.9 mm. Ring width measured in 0.1 mm may be multiplied by 2, up to a maximum ring width of 49.9 mm, converting to a diameter measurement from a radial measurement. Each increment measurement and the subtotal after each measurement may be recorded. Also, a diameter measurement may be entered (at the beginning of the core) and each annual ring subtracted from that diameter. The last recording capability of the system is a total number of measurements, or age, up to 999. For consistency in the measurements, the measurement option should be selected before the ring width measuring is started.

Sample Types

The Addo-X System is designed primarily to measure increment cores. The increment cores should be less than 200 mm in length and have a diameter greater than 4 mm and less than 5.5 mm. Currently the system can also handle increment cores mounted in blocks of wood (Haavisto 1970); it could be modified to handle most other type increment cores without much difficulty.

Cross sections 1 m to 1-1/2 m in diameter involving large amounts of wood can also be handled on the Addo-X. A normal cross section to be measured in its entirety should be less than or equal to 20 cm in diameter, and no greater than 2-1/2 cm thick. Cross sections larger than this require special preparation. The first step is to choose a radius or diameter to be measured, preferably in the field. This radius or diameter should be cut out of the cross section, leaving a portion of the cross section less than 13 cm wide, 20 cm long, and 2-1/2 cm thick. The partial cross section should be sanded, or grooved using a router or a dado blade on a table saw to make an even, uniform surface for measuring. Each portion of a large cross section should be properly labeled for later identification.

Sample Preparation

After an increment core is extracted from the tree it should be placed in a holder to prevent damage and permit labeling. A plastic drinking straw, taped or stapled at each end, works nicely for this purpose. Increment cores should be stored in a cool, dry place, making sure that the cores are not damaged. Cole (1977), in a study using lodgepole pine, recommended the increment cores be sealed tightly in a straw and frozen. This method is advised if the increment cores cannot be measured within 3 days after extraction. For most circumstances, freezing is not feasible, thus storing the cores in a cool, dry place and soaking prior to measurement, gives excellent results over long-term work. Soaking each core for at least 12 hours ensures that the entire core is a size comparable to when it was removed from the tree (table 1). This procedure also eliminates any differences in moisture content of cores taken over a summer field season.

One of the most difficult problems in handling large numbers of increment cores is properly identifying the sample. The identification code should be written on the straw in waterproof ink that will not disappear during the soaking procedure. All characters in the ID fields should be numeric to enable input through the adding machine. Special procedures can be used for entering alphabetic characters into the ID fields but require additional time.

Table 1.--*Percent radial shrinkage after air drying and resoaking increment cores*[1]

		Average percent shrinkage from original length					
		Soaking time					
Species	Air dried	1/2	1	1-1/2	2	12	24
		Hours					
Western white pine	2.22	0.39	0.39	0.17	0.37	0.70	0.31
Western larch	3.58	.58	.85	.80	.26	1.26	.60
Douglas-fir	3.51	.85	1.06	1.12	1.48	1.50	.83
Grand fir	1.80	.52	.61	.97	.98	1.81	.77
Western redcedar	1.90	.80	.74	.81	.79	.69	.58
Lodgepole pine	3.68	.92	.59	.39	1.21	.90	1.62
Subalpine fir	2.50	1.16	.99	1.28	1.43	--	1.56
Ponderosa pine	3.91	1.28	1.23	.61	1.02	--	1.63
Treatment average	2.89	.81	.81	.77	.94	1.14	.99

[1] Adapted from: Ferguson, D. E. 1977. Operating manual for measurement of tree ring growth with the Addo system. Unpublished manuscript on file at Forestry Science Laboratory, Moscow, Idaho.

Boyd[4] developed a core-slicing device that fits over the increment core holder, slicing a flat surface on the core. The core slicer should have a sharp blade and be properly adjusted to provide a clean cut. After slicing, the increment core can be read easily under the 20- or 40-power microcsope without refocusing.

As with increment cores, the label on cross section samples should contain all identification information. This information can be written on the cross section itself or attached using small metal tags. Storage of cross sections is somewhat more difficult due to their size. Cold storage is the best procedure because it minimizes check and mold. Preservatives such as moth balls included inside the sacks that contain the cross sections create an unpleasant odor for the instrument operator and do not prevent sample deterioration. Therefore, preservatives are not recommende in cross section shipment or storage.

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[4] Boyd, R. J., Silviculturist, Forestry Sciences Laboratory, Intermountain Forest and Range Experiment Station, USDA Forest Service, Moscow, Idaho (personal communicat

System Accuracy

The Addo-X system should be checked daily to make sure it is in proper adjustment. The measuring unit is influenced by decreases in line voltage that cause a decrease in the intensity of the light controlling the measuring unit, resulting in erroneous measurements. To minimize the problem the measuring unit should be connected to a separate electrical circuit. The light source should be checked each day by running a known width underneath the microscope to make sure that the light source has not faded. The keypunch machine including the drum cards should be checked daily for proper operation. A qualified repair technician should check frequently to assure the keypunch machine is properly adjusted.

Various problems may occur when measuring cores and cross sections:

1. Discontinuous or false rings are difficult to detect unless there is a cross section or more than one core is removed from the tree. The operator should be instructed as to how to handle such irregularities when recording the data.

2. The operator should be trained to take the slack out of the movable stage to assure that a proper measurement is obtained when passing over a gap or crack.

3. An error of 0.10 to 0.15 mm can be introduced in a measurement if the focus of the microscope is changed while measuring an annual ring.

4. Allowing the control switch for the entire system to rebound will cause erroneous measurements.

5. It is possible to operate the measuring unit faster than the adding machine and the keypunch can process the measurements. Therefore, each measurement should be completely through the system before the next measurement is entered.

When compared with measurements taken in the field the Addo-X measurements have greater accuracy. This may lead to some problems in analyzing the data. If differences in growth or age are required in the analysis, the same technology should be used for the two measurements used in determining the difference. For example, to find the difference between age at breast height and age at the base of the live crown, the same technology should be used in measuring the age at both places. The Addo-X should not be used at one point and a hand count in the field used at the other point. This procedure often leads to an error in the differences.

Time and Cost

The Addo-X system is an efficient system for handling large numbers of increment cores. In an hour, an experienced operator can measure approximately 15 increment cores less than 5 cm long, or about 10 cores 5-to 15-cm long (table 2). However, length of the core is not as important as the number of annual rings in determining the amount of time required for measuring. The time required for preparing increment cores is a small amount of the total measuring process.

Table 2.--*Time and cost of measuring increment cores and cross sections with the Addo-X system*

Sample type	Sample preparation	Measurement	Editing and corrections	Total cost sample ($)[1]
Cores (length)				
≤ 5 cm	Nominal	15/h	1 h/2000 cards	$0.34
> 5 cm	Nominal	10/h	1 h/2000 cards	.50
Cross sections[2] (diameter)				
≤ 5 cm	60/h	20/h	1 h/2000 cards	.34
5-35 cm	30/h	15/h	1 h/2000 cards	.50
> 35 cm[3]	2/h	2/h	1 h/2000 cards	5.00

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[1] Costs include sample preparation, measuring, operator, and equipment maintenance

[2] Radii per cross section.

[3] 200-300 annual rings.

For cross sections less than 5 cm in diameter, about 60 cross sections per hour may be prepared and up to 30 cross sections (2 radii) per hour may be measured with the Addo-X. For cross sections 5 cm to 35 cm in diameter, 30 per hour may prepared and approximately 15 per hour (2 radii) may be measured. For cross sections greater than 35 cm (over 200 years old), more preparation is required, and approximately two per hour may be prepared, and two per hour (2 radii) measured.

The above examples are averages from the many thousands of cores and hundreds of cross sections that have been measured at the Moscow laboratory using the Addo-X system.

Data Editing

The data editing normally required on a set of Addo-X data involves checking for such things as the proper sample identification and plot numbers. Also, a check is made to determine that each one of the subtotals is increasing in size. A computer program used for data editing is provided in the appendix.

CONCLUSIONS

From past experience in measuring thousands of cores of all sizes and many hundre of cross sections, the Addo-X system has been shown to be fast and accurate. This system minimizes the chance for transcription error or normal operator error such as may occur when using a ruler or other types of measuring devices. Also, this system provides a machine readable output in the form of punched cards, which can be read directly by a computer for checking and analysis.

The most important part of the entire procedure is proper sample preparation. It may take longer to prepare the samples (cross sections), make sure that the ID fields are correct, and transcribe any information that may not be included with the sample than it does to actually measure the sample. As mentioned before, the operator can usually operate the Addo-X system faster than the keypunch and adding machine can accept the information.

Personnel may be easily trained to use the equipment. After one day of operation, most operators can accurately measure increment cores or cross sections. The cost per sample is very reasonable for the accuracy obtained (table 2). Many types of measurements have been taken with the Addo-X system, and it may be adapted to almost any radial increment measurements or age determination.

PUBLICATIONS CITED

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Haavisto, V. F.
1970. A multiple core holder for Addo-X. For. Chron. 46(3):194-195.

APPENDIX
COMPUTER PROGRAM FOR SCREENING ADDO-X DATA

```
      DIMENSION IALL(80),NALL(80)
C     THIS IS AN EXAMPLE OF A COMPUTER PROGRAM WE USED TO SCREEN
C     DATA GENERATED BY THE ADDO SYSTEM.  OTHER JOBS REQUIRE
C     WRITING A NEW COMPUTER PROGRAM BUT GENERAL CONCEPTS
C     EXPLAINED BELOW WOULD APPLY.  THE SAMPLING DESIGN WAS
C     TWO HUNDRED 10 OR 14 POINT CLUSTERS.  ON EACH POINT
C     COMBINATIONS OF 10 DIFFERENT TREE SPECIES COULD OCCUR.
C     EACH TREE WAS CONSECUTIVELY NUMBERED, SPECIES WAS
C     RECORDED, AND TWO INCREMENT CORES WERE EXTRACTED
C     FROM EACH TREE.  THE SUBTOTALING METHOD WAS USED TO
C     RECORD THE DATA ON COMPUTER CARDS.
C
      N=0
C     COMPUTER CARD FORMAT:
C    VARIABLE  COLUMN   EXPLANATION
C    --------  ------   -----------
C       ICL      1-3    CLUSTER NUMBER.  RANGE IS FROM 1 THROUGH 200.
C       IPT      4-5    POINT NUMBER.  UP TO 14 POINTS PER CLUSTER.
C       ITRE     6-7    TREE NUMBER.  ALTHOUGH THIS VARIES FROM
C                       POINT TO POINT, THE MAXIMUM WAS ABOUT 20
C                       TREES PER POINT.
C       ICORE    8-9    CORE NUMBER.  THIS MUST BE EITHER CORE #1
C                       OR CORE #2.
C       ISPP    10-11   SPECIES CODE.  RANGE IS FROM 1 THROUGH 10.
C       I          12   COLUMN 12 WAS SKIPPED ON THE COMPUTER CARD.
C                       IT SHOULD ALWAYS BE BLANK.
C       I1      13-17
C       .         .
C       .         .
C       .         .
C       I13     73-77   THIRTEEN 5-DIGIT SUBTOTAL FIELDS.
C      IAGE     78-80   TREE AGE.  AGE VARIES BUT MAXIMUM WAS ABOUT
C                       150 YEARS.  AGE WAS NOT ALWAYS OBTAINABLE.
C
      READ(5,100) ICL,IPT,ITRE,
     ,ICORE,ISPP,I,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,IAGE,IALL
      GO TO 1
C
C     READ COMPUTER CARD.  BRANCH TO STATEMENT '999' AT END OF DATA.
C
   10 READ(5,100,END=999) ICL,IPT,ITRE,
     ,ICORE,ISPP,I,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,IAGE,IALL
C
C     CHECK FOR INCREMENTATION FROM ONE CARD TO ANOTHER
C
      IF(ICL.EQ.NCL.AND.IPT.EQ.NPT.AND.ITRE.EQ.NTRE.AND.ICORE.EQ.NCORE.
     , AND.ISPP.EQ.NSPP.AND.N13.GE.I1) WRITE (6,112) NALL,IALL
C
C     CHECK FOR CLUSTER VALUES OUTSIDE THE RANGE 1 THROUGH 200
C
    1 IF(ICL.GT.200.OR.ICL.LT.1) WRITE(6,102) IALL
C
C     CHECK FOR PLOT VALUES OUTSIDE THE RANGE 1 THROUGH 14
C
      IF(IPT.GT.14.OR.IPT.LT.1) WRITE(6,104) IALL
```

```
C
C     CHECK FOR TREE NUMBERS OUTSIDE THE RANGE 1 THROUGH 20
C
      IF(ITRE.GT.20.OR.ITRE.LT.1) WRITE(6,105) IALL

C
C     CHECK FOR CORE NUMBERS NOT EQUAL TO '1' OR '2'
C
      IF(ICORE.LT.1.OR.ICORE.GT.2) WRITE(6,106) IALL
C
C     CHECK FOR SPECIES CODES OUTSIDE THE RANGE 1 THROUGH 10
C
      IF(ISPP.GT.10.OR.ISPP.LT.1) WRITE(6,107) IALL
C
C     CHECK FOR ANY PUNCHES IN COLUMN 12 - IT SHOULD BE BLANK
C
      IF(I.NE.0) WRITE(6,108) IALL
C
C     CHECK FOR NO VALUE ENTERED IN FIRST FIELD.  THIS WOULD INDICATE A
C     CARD WITH NO MEASUREMENTS ON IT.
C
      IF(I1.LE.0) WRITE(6,109) IALL
C
C     CHECK FOR INCREMENTATION ACROSS THE CARD
C
      IF(I2.LE.I1.AND.I2.NE.0)    WRITE(6,103) IALL
C
      IF(I3.LE.I2.AND.I3.NE.0)    WRITE(6,103) IALL
C
      IF(I4.LE.I3.AND.I4.NE.0)    WRITE(6,103) IALL
C
      IF(I5.LE.I4.AND.I5.NE.0)    WRITE(6,103) IALL
C
      IF(I6.LE.I5.AND.I6.NE.0)    WRITE(6,103) IALL
C
      IF(I7.LE.I6.AND.I7.NE.0)    WRITE(6,103) IALL
C
      IF(I8.LE.I7.AND.I8.NE.0)    WRITE(6,103) IALL
C
      IF(I9.LE.I8.AND.I9.NE.0)    WRITE(6,103) IALL
C
      IF(I10.LE.I9.AND.I10.NE.0)  WRITE(6,103) IALL
C
      IF(I11.LE.I10.AND.I11.NE.0) WRITE(6,103) IALL
C
      IF(I12.LE.I11.AND.I12.NE.0) WRITE(6,103) IALL
C
      IF(I13.LE.I12.AND.I13.NE.0) WRITE(6,103) IALL
C
C     CHECK FOR AGE GREATER THAN 150 YEARS
C
      IF(IAGE.GT.150) WRITE(6,111) IALL
C
C     INCREMENT THE CARD COUNTER
C
      N=N+1
```

```
C
C     SAVE VALUES OF CARD JUST READ TO CHECK FOR INCREMENTATION ON
C     CONTINUATION CARD
C
      NCL=ICL
      NPT=IPT
      NTRE=ITRE
      NCORE=ICORE
      NSPP=ISPP
      N13=I13
      DO 2 I=1,80
    2 NALL(I)=IALL(I)
C
C    RETURN AND READ A NEW CARD
C
      GO TO 10
  999 CONTINUE
C
C     WRITE OUT NUMBER OF CARDS SCREENED
C
      WRITE(6,114) N
C
C     FORMAT STATEMENTS
C
  100 FORMAT(I3,4I2,I1,13I5,I3,T1,80A1)
  102 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- CLUSTER')
  103 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- INCREMENTATION')
  104 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- POINT')
  105 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- TREE #')
  106 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- CORE #')
  107 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- SPECIES')
  108 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- COL 12 NOT BLANK')
  109 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- FIRST FIELD ZERO')
  111 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- AGE EXCEEDS 150 ')
  112 FORMAT('0',3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,/,' ',    3A1,1X,4(2A1,1X),A1,1X,7(5A1,1X),/,T20,6(5A1,1X),3A1,3X
     ,,'<-- CARD SEQUENCE')
  114 FORMAT('0NUMBER OF CARDS SCREENED = ',I6)
      STOP
      END
```

SAMPLE DATA WITH ERRORS UNDERLINED

```
20005020201 0009100241003790050100659008070096501106012470136601485
20005020201 001180026800421005410038000820009510107001193013220140201479       015
                                --------
20001030201 000670014600229003220040200479005380061200689007740085800940       015
20302060201 00097002330036100473005570073800900010750124601411
---
20009070201 0007200179002640034500473005770068900797009350107701198013090141 6
20009070201 01101                                                              015
            -----
20002050289 0009100199003170042100520006240073200843009210100501088011860128 2
         --
20006060101 00092002590041200508006610080600934010510116601265                 014
20005207 0101 000330010500203002800037100465005480064600754008600094701056       014
   --
20003030101 00045001220016000216002980041300509005970070500799008730094301021
20003030101 01048                                                              014
20008030231 000950024400382005230065000757008790098601121012520138201486
         --
20006050201 000780019900314003950049900590006630074800846009500102701104       214
                                                                               ---
20009060201 00071002080032500443005700069500786008890002001153012960142501559
                                                    -----
20009660201 01680
     --
20003030201100076001940031600424005390065600761008620094801046011280121201276014
           -
20021040201 000720018000264003430042700519006210072000829009440105501173
   --
20009040201 00082002170015600491006540080400746010760122801363015160165501790
                      -----               -----
20009040201 00000
            -----
20006050101 0009200205003210041500511006200072500816009190102001102            614
                                                                               ---
```

```
                    SCREENED COMPUTER OUTPUT

200 05 02 02 01   00118 00268 00421 00541 00380 00820 00951
                  01070 01193 01322 01402 01479       015     <-- INCREMENTATION
203 02 06 02 01   00097 00233 00361 00473 00557 00738 00900
                  01075 01246 01411                           <-- CLUSTER
200 09 07 02 01   00072 00179 00264 00345 00473 00577 00689
                  00797 00935 01077 01198 01309 01416
200 09 07 02 01   01101
                                                      015     <-- CARD SEQUENCE
200 02 05 02 89   00091 00199 00317 00421 00520 00624 00732
                  00843 00921 01005 01088 01186 01282         <-- SPECIES
200 52 07 01 01   00033 00105 00203 00280 00371 00465 00548
                  00646 00754 00860 00947 01056       014     <-- POINT
200 08 03 02 31   00095 00244 00382 00523 00650 00757 00879
                  00986 01121 01252 01382 01486               <-- SPECIES
200 06 05 02 01   00078 00199 00314 00395 00499 00590 00663
                  00748 00846 00950 01027 01104       214     <-- AGE EXCEEDS 150
200 09 06 02 01   00071 00208 00325 00443 00570 00635 00786
                  00889 00020 01153 01296 01425 01559         <-- INCREMENTATION
200 09 66 02 01   01680
                                                              <-- TREE #
200 03 03 02 01 1 00076 00194 00316 00424 00539 00656 00761
                  00862 00948 01046 01128 01212 01276 014     <-- COL 12 NOT BLANK
200 21 04 02 01   00072 00180 00264 00343 00427 00519 00621
                  00720 00829 00944 01055 01173               <-- POINT
200 09 04 02 01   00082 00217 00156 00491 00654 00804 00746
                  01076 01228 01363 01516 01655 01790         <-- INCREMENTATION
200 09 04 02 01   00082 00217 00156 00491 00654 00804 00746
                  01076 01228 01363 01516 01655 01790         <-- INCREMENTATION
200 09 04 02 01   00082 00217 00156 00491 00654 00804 00746
                  01076 01228 01363 01516 01655 01790
200 09 04 02 01   00000
                                                              <-- CARD SEQUENCE
200 09 04 02 01   00000
                                                              <-- FIRST FIELD ZERO
200 06 05 01 01   00092 00205 00321 00415 00511 00620 00725
                  00816 00919 01020 01102             614     <-- AGE EXCEEDS 150
NUMBER OF CARDS SCREENED =      20
```

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 273 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

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COMPARATIVE GROWTH RATES OF WESTERN WHITE PINE VARIETIES RESISTANT TO BLISTER RUST

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ABSTRACT

Compared was the growth of seedlings of western white pine that displayed specific mechanisms of resistance in response to white pine blister rust. These growth statistics were then compared to those of seedlings that had blister rust cankers. No difference was detected among these categories.

KEYWORDS: Resistance, white pine blister rust, western white pine.

Breeding for resistance in western white pine (*Pinus monticola*) to white pine lister rust (caused by *Cronartium ribicola*) started in 1950. By 1974, a grafted eed orchard, three seedling seed orchards, and a breeding arboretum were established.

Mechanisms of resistance to blister rust were of several types (Bingham and thers 1973; Hoff and McDonald, in press). One question frequently asked was: What s the impact of these various mechanisms on other traits, mainly growth? This aper compares the growth rates of young white pines in a natural forest that contain arious mechanisms of resistance.

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MATERIALS AND METHODS

The trees used in this study were grown from seed planted in the nursery at Moscow, Idaho, in 1964, 1965, and 1966. Seedlings were from phenotypically blister rust resistant parents growing in natural stands. The seedlings were the first generation (F_1) produced after selection by blister rust. The second generation seedlings (F_2) were produced from the F_1 seedlings that survived intense artificial inoculation with blister rust. This inoculation took place when the seedlings were two years old, using methods described by Bingham (1972). To determine presence or absence of blister rust fungus, and to identify any resistance mechanisms, inspections were conducted using procedures described by Hoff and McDonald (in press).

In 1971, the surviving seedlings were labeled, lifted, and outplanted in the Canyon Creek drainage of the Priest River Experimental Forest in north Idaho. The site, a gently sloping stream bottom aluvial plain, supports the Hemlock-Pachistima type vegetation. The seedlings were planted 8 feet apart in a random design.

The trees were measured in 1976 and 1977. Data are presented for 1976 height, and 1977 growth adjusted for 1976 height. The adjustment was made because trees when planted were of various heights due to rust resistance testing methods, because trees broke out of transplanting shock at different times, and because cankered trees were about 10 percent shorter than noncankered ones.

The data are grouped by the year seedlings were sown in the nursery (1964, 1965, 1966) progeny type (F_1, F_2, self), and by the following mechanisms of resistance

1. No needle spots and no cankers: fungus did not infect the tree in any manner.

2. Needle spots only: fungus infected needles but was killed or eliminated before it could enter the stem.

3. Stem symptoms: fungus infected needles and grew into stem but was killed soon after entering stem, leaving a readily noticeable reddish-brown dead patch of stem tissue.

4. Canker death: fungus developed extensively but was then killed.

5. Cankered: fungus fully progressed from needle spots to typical stem canker; however, slowing of fungus growth or tolerance for the rust allowed tree to survive.

RESULTS AND DISCUSSION

Total 1976 height and adjusted 1977 growth are tabulated in tables 1, 2, and 3.

Trees that were cankered (category 5) were 10-15 percent shorter than those noncankered. There was little difference, however, between cankered and noncankered in the adusted 1977 growth. For some reason cankers affected the early growth of these trees but not later growth. Bingham and others (1973) report that cankers did not affect the growth of young trees. In fact, the infected trees were slightly taller. Transplanting the fairly large stock (trees 6, 5, and 4 years old) may have had more adverse affects on the cankered trees.

Table 1.--*Mean adjusted 1977 growth and total 1976 height of western white pine* F_1 *trees infected with blister rust or not infected because of several mechanisms of resistance*

Mechanism of resistance	1964 PT*		Total height 1976	1965 PT*		Total height 1976
	Trees	77 growth		Trees	77 growth	
	No.	*cm*	*cm*	*No.*	*cm*	*cm*
No spots, no cankers	671	29	100	141	32	119
Needle spots only	641	29	104	70	31	117
Stem symptoms	770	29	99	57	32	114
Canker death	440	28	104	65	33	116
Cankered	48	27	85	-	-	-
Total	2570	$\bar{x}$ 29	101	333	$\bar{x}$ 32	117

*1964 PT (progeny test), 1965 PT seed were sown in autumn 1964 and 1965, respectively.

Table 2.--*Mean adjusted 1977 growth and total 1976 height of western white pine* F_2 *trees infected with blister rust or not infected because of several mechanisms of resistance*

Mechanism of resistance	1965 PT*		Total height 1976	1966 PT*		Total height 1976
	Trees	77 growth		Trees	77 growth	
	No.	*cm*	*cm*	*No.*	*cm*	*cm*
No spots, no cankers	98	33	115	184	27	94
Needle spots only	60	33	116	761	27	92
Stem symptoms	29	29	121	63	27	93
Canker death	50	31	103	33	25	92
Cankered	-	-	-	47	27	84
Total	237	$\bar{x}$ 32	114	1088	$\bar{x}$ 27	92

*1965 PT and 1966 PT seed were sown in autumn 1965 and 1966, respectively.

Table 3.--*Mean adjusted 1977 growth and total 1976 height of western white pine selfed trees infected with blister rust or not infected because of several mechanisms of resistance*

Mechanism of resistance	1964 PT*		Total height 1976	1965 PT*		Total height 1976
	Trees	77 growth		Trees	77 growth	
	No.	*cm*	*cm*	*No.*	*cm*	*cm*
No spots, no cankers	109	20	67	22	20	80
Needle spots only	82	19	70	-	-	-
Stem symptoms	85	21	71	-	-	-
Canker death	34	20	81	11	24	82
Cankered	4	18	60	-	-	-
Total	314	$\bar{x}$ 20	70	44	$\bar{x}$ 22	81

*1964 PT, 1965 PT seed were sown in fall of 1964 and 1965, respectively.

Among the noncankered categories no consistent pattern emerged in the variation of total height. And after adjustment of 1977 growth on 1976 total height, differences among all categories were insignificant.

For the F_1 progenies in the 1964 test, correlations between traits were as follows:

1. Resistance types and 1976 height r = 0.003 N.S.

2. Resistance types and 1977 growth r = 0.015 N.S.

3. Resistance types and 1977 adjusted growth r = 0.021 N.S.

4. 1976 height and 1977 growth r = 0.65 signif. 0.001.

One weakness in this test is that there were no truly susceptible control plants. They all died from blister rust in the nursery or soon after outplanting. The trees most closely approximating a control group were those with living cankers, but even these are probably still alive because of some resistance or tolerance to the fungus. Nevertheless, it seems unlikely that if blister rust resistance were negatively related to growth that it would occur uniformly over all resistance types. Further, Bingham and others (1973) found no difference in young seedling growth among controls and F_1 and F_2 blister rust resistant stock. The controls were standard nursery stock with little or no resistance. Thus, we conclude (within the limits of the data presented) that growth rate and resistance to blister rust are independently inherited characteristics.

In addition, we have not noticed any association between resistance types and other traits such as tree form or the occurrence of other pests.

We intend to measure the trees in the plantation every 5 years and to continue looking for associations between resistance types and other traits.

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