canusa

Canada
United States
Spruce Budworms
Program

United States Department of Agriculture
Forest Service
Intermountain Forest and Range Experiment Station
Research Note INT-330
June 1983

Deploying Pheromone-Baited Traps for the Western Spruce Budworm and Other Defoliating Insects[1]

David G. Fellin and Paul W. Hengel[2]

ABSTRACT

A procedure is described in which pheromone traps are mounted on poles to be used in studies where it is not desirable to hang traps from tree limbs or in study areas where trees are widely spaced or absent. Both Pherocon II and 1/2-gallon milk carton traps can be deployed by affixing them with hangers made of #9 galvanized wire to the top of 6-ft poles made of 3/4-inch PVC pipe which are set into the ground.

KEYWORDS: *Choristoneura occidentalis* Freeman, western spruce budworm, pheromones, dispersal, flight behavior

In recent years, forest entomologists in the western United States have used various pheromone-baited traps for surveys and research with several species of defoliating insects, particularly the western spruce budworm, *Choristoneura occidentalis* Freeman (Cory and others 1982), the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McD) (Daterman 1978), and the European pine shoot moth, *Rhyacionia buoliana* (Schiff.) (Daterman 1974).

Researchers and surveyors usually hang the traps from the lower limbs of conifers with some type of plastic or wire hanger. To prevent wind from blowing traps about or into dense foliage, traps are wired close to and crosswise under tree branches, and the foliage near the ends of the trap is trimmed off (Daterman and others 1979) as shown in figure 1.

In recent years, we have been studying the effects of various silvicultural and stand management practices on the local dispersal and flight behavior of the western spruce budworm in forested areas ranging from clearcuts to undisturbed stands. Often there are no trees growing from which to hang the traps. Moreover, hanging traps from tree limbs can be disadvantageous in that moth catches will be increased by attaching traps to budworm-infested trees (Liebhold and Volney 1982). Therefore, we were forced to devise some kind of system that would allow us to deploy our pheromone-baited traps exactly where we wanted them. This paper describes the method we now use to deploy two types of pheromone-baited traps.

---

[1] Research leading to this publication was funded in part by the USDA Forest Service Canada-United States Spruce Budworms Program, Washington, D.C.

[2] Supervisory Research Entomologist and Biological Technician, Forestry Sciences Laboratory, Intermountain Forest and Range Experiment Station, USDA Forest Service, Missoula, Mont.

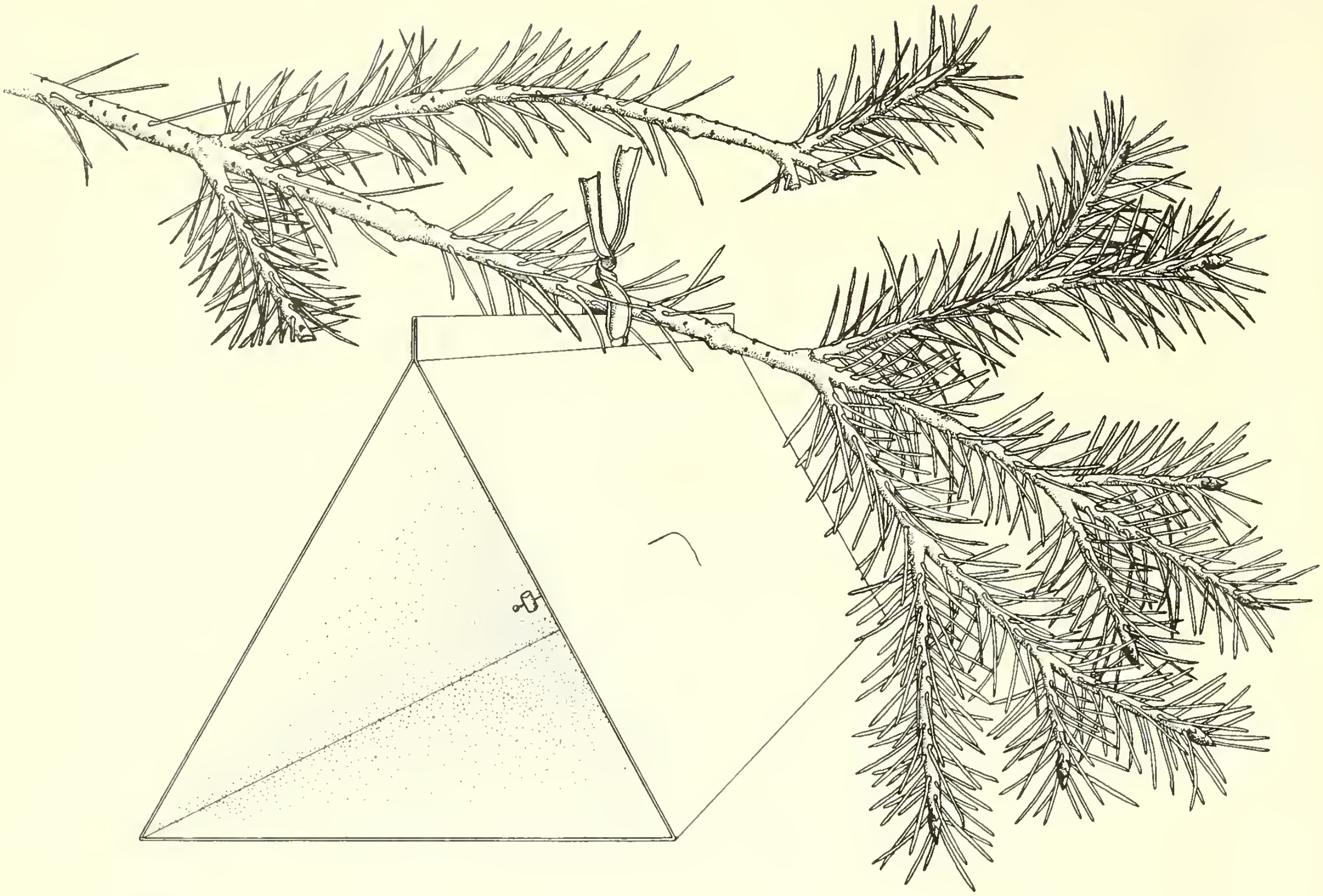


Figure 1.—Trap modified from 1/2-gallon milk carton baited with a pheromone and suspended from limb of Douglas-fir. Traps are wired crosswise and close to limb and adjacent branches trimmed off. Pin holding pheromone bait is bent over to prevent it from slipping out. This is the type of pheromone-baited trap generally used by forest entomologists in the western United States.

PREPARING TRAPS, HANGERS, AND POLES

Preparing the Traps

In 1978 we used standard, general purpose, white, fold-open Pherocon II adhesive traps[3] (formerly called Sectar I).[4] Since 1979 we have used a triangular-structured trap as described by Daterman (1978) that was modified from a 1/2-gallon (imperial measure) paper milk carton.[5] We changed to the milk carton traps in 1979 because they cost less, are simple of design, and because these types of traps are being used by other investigators West-wide. With both types of traps we coated the interior walls with a sticky material (TACK TRAP). In the case of the Pherocon II traps, the TACK TRAP was in addition to the sticky material already applied to the traps by the manufacturer. The only other modification we made on the Pherocon II trap was to punch a 1/4-inch diameter hole, 3/16 inch up from the bottom edge of the trap and centered lengthwise.

Paper milk carton stock was purchased[6] unassembled, without stickum, and unfolded, but with the fold lines scribed. The stock was cut so that when laid out flat, it consisted of three 10-1/2- × 3-3/4-inch rectangular surfaces, with a 3/4-inch margin on each end. The center surface forms the bottom, and the other two surfaces form the sides of the assembled trap. The two sides are brought together and two 1/4-inch holes are punched in the 3/4-inch margin, 1/2 inch in from each end and 1/2 inch down from the top. The trap is then laid out flat and the surfaces that will form the interior are uniformly coated with TACK TRAP. The sides are then folded closed and the 3/4-inch uncoated edges are stapled together to form the top of the trap.

Preparing the Hangers

Hangers for both types of traps are made from #9 galvanized wire. The wire is cut with an 8-inch mill bastard, rather than wirecutters, and the ends are rounded and smoothed with an electric grinder. The wires for the Pherocon II trap are cut into

---

[3] Available commercially from Zoecon Corporation, Pherocon Supply Services, 925 California Avenue, Palo Alto, CA 94304.

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

[5] Available from Animal Repellants Inc., 1016 Everee Road, Griffin, GA 30223.

[6] Available either from Weyerhaeuser Company, Carton Division, P.O. Box 1826, Vancouver, WA 98663, or from International Paper Co., 401 Kindelberger Road, Kansas City, KS 66115.

11-5/8-inch pieces and those for the milk carton traps into 11-7/8-inch pieces. The hangers for each type of trap are formed by carefully bending wire segments at different angles of bend, all bends in the same plane (fig. 2). Angles of bend must closely conform to the specifications if the hangers are to firmly attach the traps to the support poles.

Preparing the Support Poles

For both types of traps, the support poles consist of heavy-duty 3/4-inch PVC plastic pipe commercially available in 20-ft lengths. From each length we cut three 6 ft 8-inch lengths, using a fine-tooth crosscut blade on a radial arm saw. (Blades with large teeth break or shatter the pipe.) Early in our studies we tried using 1/2-inch PVC pipe, but it was too flexible and provided less support than the 3/4-inch pipe. One end of each piece is cut square (at right angles to the pipe length); the other end is cut at an angle of 50 degrees to ease entry of the pipe into the ground.

In preparing poles for the Pherocon II traps, first a slot is cut in the top of the pole, 1/2 inch deep and 5/32 inch from one side of the pole, using a band saw equipped with a 1/16-inch blade. Two wooden stops are installed on the band saw platform against which the pipe is guided, to insure an accurate and uniformly cut slot.

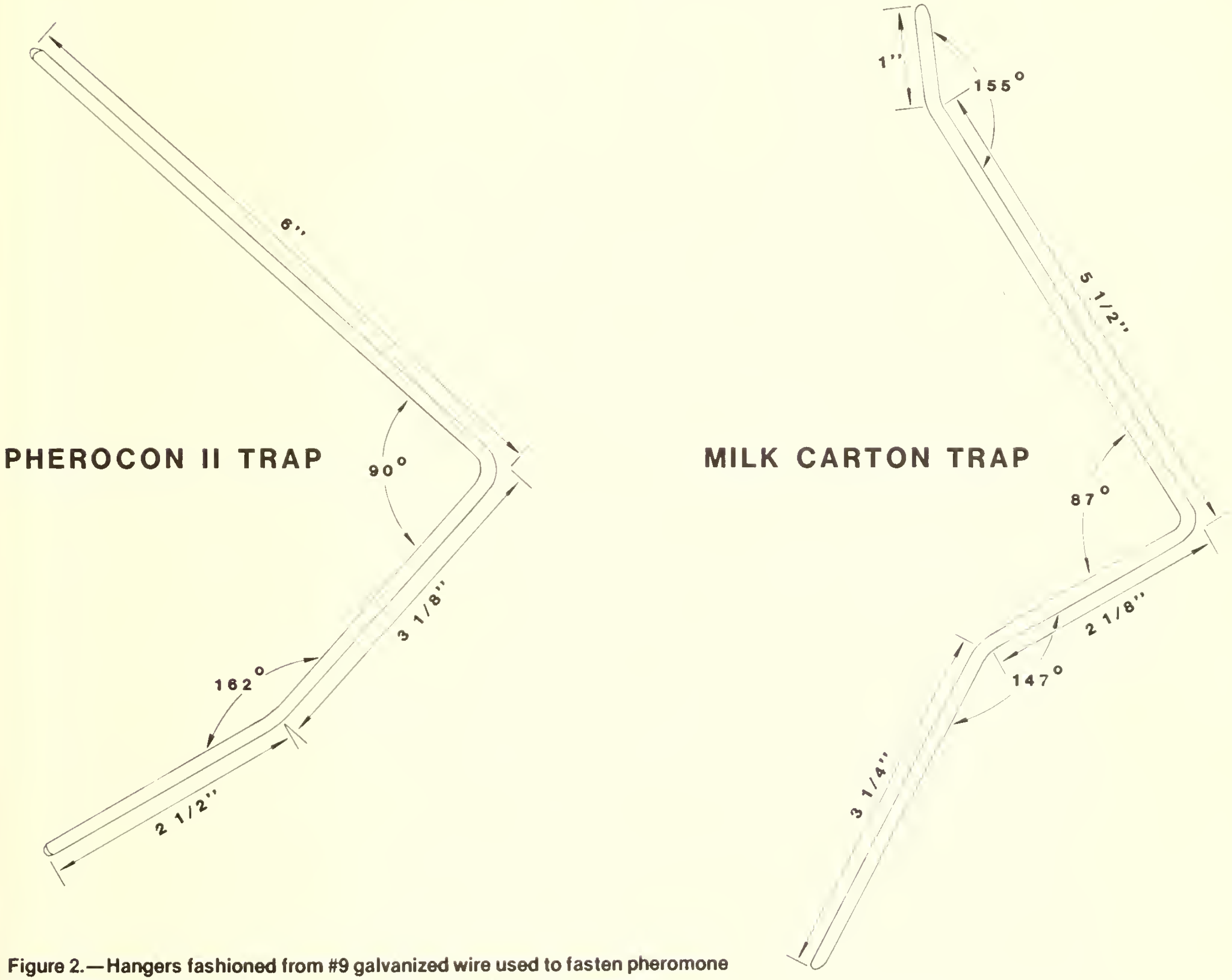


Figure 2.—Hangers fashioned from #9 galvanized wire used to fasten pheromone traps to the top of support poles, showing lengths of each wire segment and angles of bend. Hanger for Pherocon II traps (left); hanger for 1/2-gallon paper milk carton trap (right). Two hangers are used for each 1/2 gallon trap.

After the slot is cut, two holes are drilled in the top of the pole, the first hole centered between the two slots. The location of the holes drilled is critical to insure a secure attachment of the traps. Therefore all holes are drilled using a drill press equipped with a 5/32-inch bit (the same diameter as the wire hangers) and a supporting jig (fig. 3) to hold the poles while drilling. The jig is bolted to the drill press platform so that when the poles are cradled in the mortised surface and abutted against the metal stop, the pole is very precisely positioned beneath the drill bit. The drill press is lowered slowly; otherwise the bit, even though sharp, has a tendency to slide around on the smooth surface of the PVC pipe before penetrating, which results in mispositioned and irregularly shaped holes. Once the slot has been cut and the holes drilled, the preparation of the pole for the Pherocon II trap is complete.

The procedure for preparing the poles for the 1/2-gallon milk carton traps is very similar to that for the Pherocon II trap poles except that no slot is cut in the pole and, using the same jig, four holes are drilled instead of two. Once the first two holes have been drilled, the pole is rotated 180 degrees, a straight piece of hanger wire is inserted through the holes and slightly into the 2 × 4 to hold the pole steady. The second set of holes is then drilled from the opposite side of the pole as the first two. Once the four holes have been drilled, the preparation of the pole for the milk carton traps is complete.

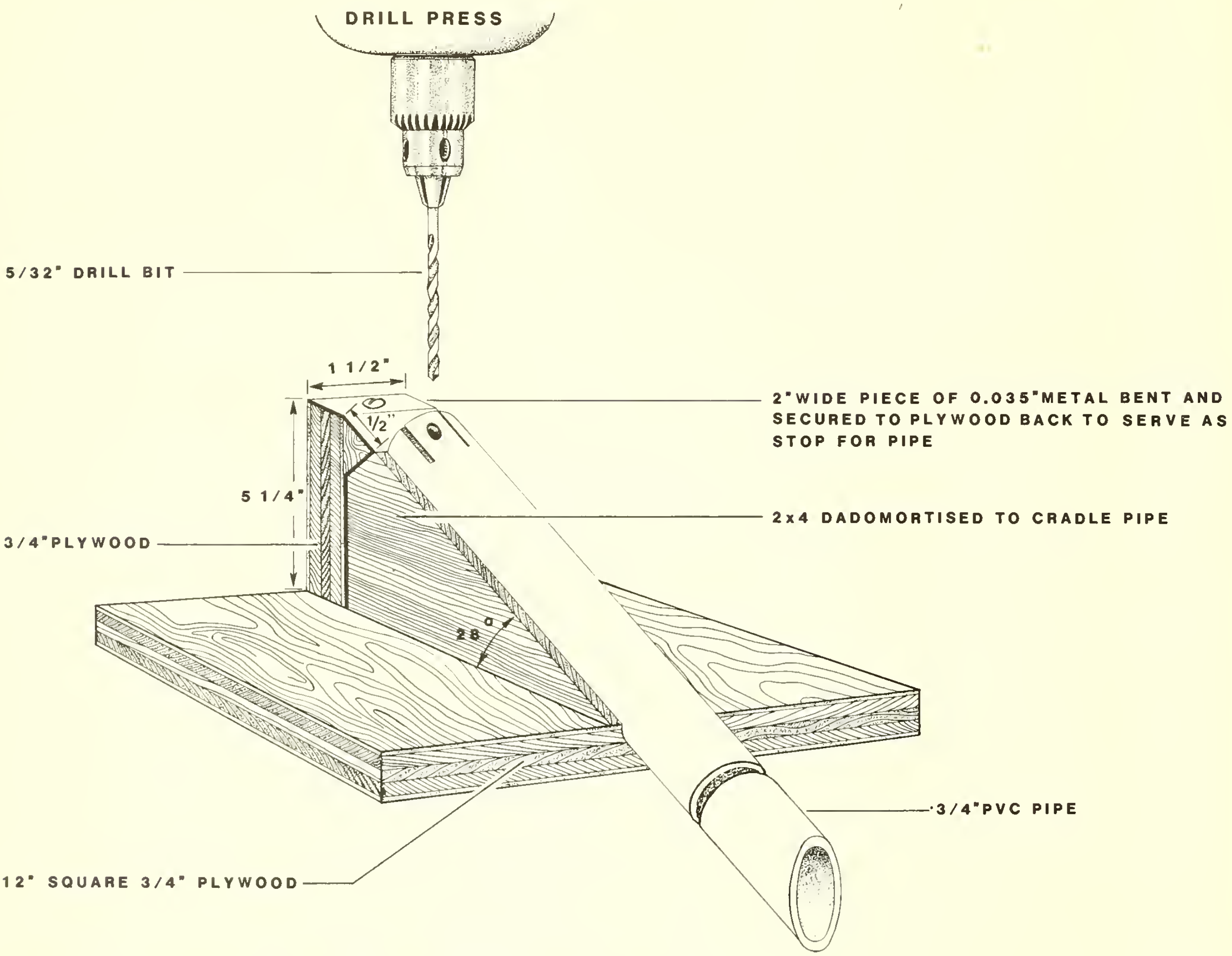


Figure 3.—Jig and drill press setup for drilling hanger holes in top of pipe. Jig is precisely positioned and bolted to base of drill press so as the bit is lowered it enters upper surface of pipe exactly 3/16 inch from uppermost edge and exits lower surface of pipe 3/4 inch from uppermost edge. Pole lying in cradle has been drilled and is prepared for attachment of Pherocon II trap.

TRAP DEPLOYMENT

At the forest sampling site a digging bar with a diameter slightly larger than the PVC pipe-poles is used to punch a hole into the forest soil, 1 ft to 1-1/2 ft deep. The pole is thrust firmly into the hole and twisted into the ground, then the soil tamped with the dull end of the bar. Poles will shatter if driven into the ground with a driving maul. When poles are in place, their tops are usually 5 ft to 5-3/4 ft above the forest floor. Traps are labeled with the appropriate plot location, date, etc., with an indelible felt marker, then affixed with the wire hangers to the top of the pole.

To attach the Pherocon II trap, the bottom of the trap is centered and pulled down into the slot until the bottom of the trap is flush with the bottom of the slot and the hole punched in the trap bottom is centered over the hole drilled in the pole. Holding the 6-inch length of hanger upright, the shorter hanger arm is thrust through the holes in the pipe and the hole in the trap until the 18-degree bend abuts the pipe. The trap is then extended upward and the end of the 6-inch hanger arm slipped through the hole in the top of the trap. The trap is then slid back on the 6-inch length until the trap contacts the 90-degree bend in the hanger, allowing at least 1-1/2 inches of the wire protruding beyond the hole in the top of the trap (fig. 4). Finally, the insect pin, on which the pheromone has been impaled, is thrust through the center of one side of the trap using a pair of long-nosed pliers.

To attach the 1/2-gallon milk carton trap, the 3-1/4-inch segments of each of the two wire hangers are inserted, respectively, through the upper two holes down into the lower set of holes until the 147-degree bend of each wire abuts against the pole. At this point each 2-1/8-inch segment is horizontal and the 5-1/2-inch segment is vertical and, affixed to the pole, resembles a football field goalpost. The trap is then set on top of the pole, and the vertical wires turned, respectively, until they lay against either side of the trap. Each 1-inch wire segment is then slipped from opposite sides into the hole at either end of the top of the trap (fig. 5). Once the trap is affixed to the top of the pole, the pheromone-bearing insect pin (Daterman 1974) is thrust from the inside through one side of the trap. It is a little more difficult than with the Pherocon II trap to center the pin since the milk carton trap is considerably longer.

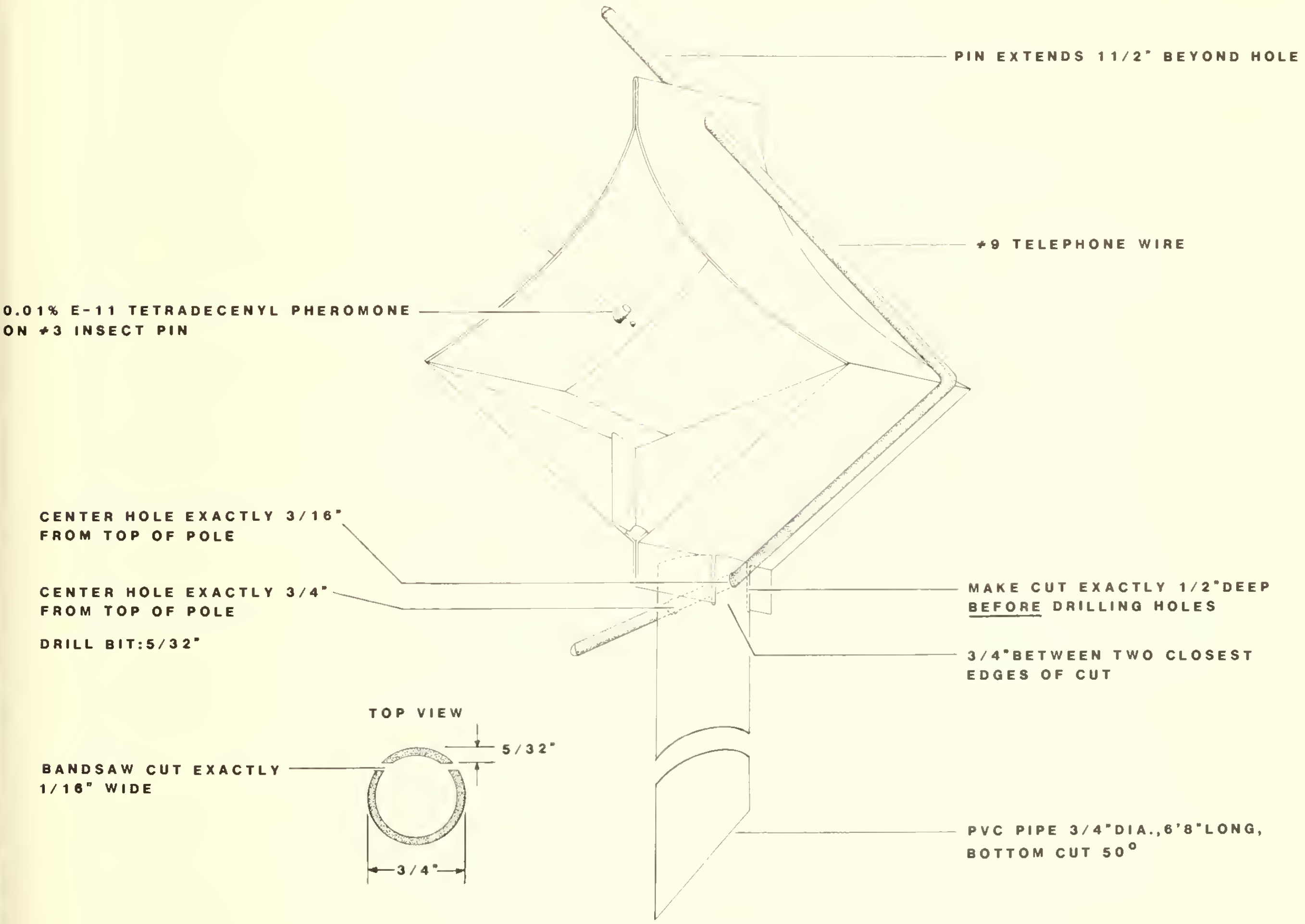


Figure 4.—Pheromone-baited Pherocon II trap mounted to the top of a 3/4-inch PVC plastic pole with a single wire hanger. Top view of pole (left) shows slot cut in pole into which bottom of trap is inserted.

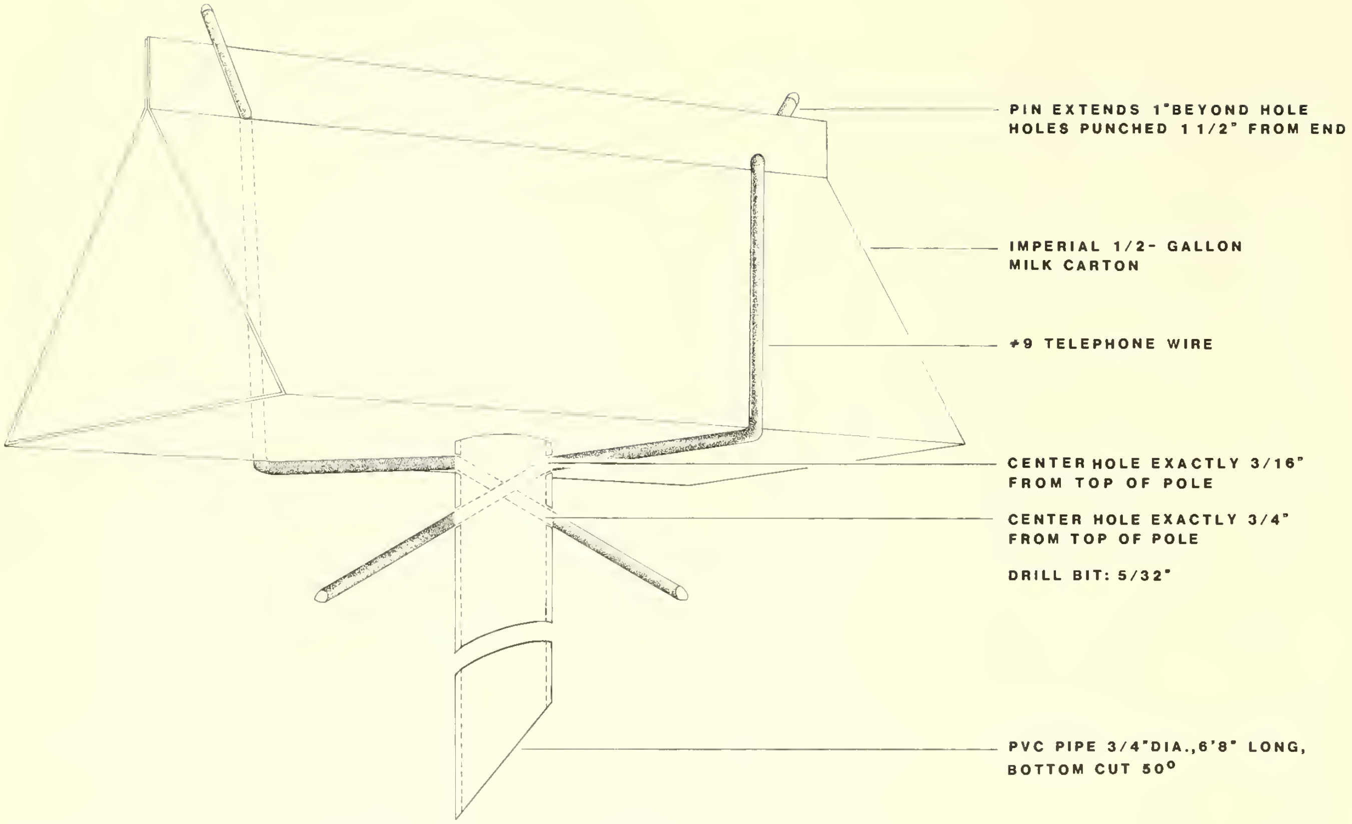


Figure 5.—Pheromone-baited milk carton trap mounted to the top of plastic pole with two wire hangers.

DISTRIBUTION OF TRAPS IN STUDY AREAS

The distribution of traps in any study area will depend on the objectives and needs of individual investigators. For our research during the summers of 1978 and 1979, we deployed a total of 746 traps of both types in 11 different study areas; in 1978, 298 Pherocon II traps were deployed, and in 1979, 445 1/2-gallon milk carton traps were set out. We deployed traps at all study areas so that traps were placed no closer than 100 ft to one another; each trap represented at least 0.33 acre.

This sampling intensity was based on preliminary sampling in an 11-acre clearcut where we had established 32 sampling points on roughly 100 ft-centers, and in consultation with Dr. Gary Daterman (USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.). We concluded that a 0.01 percent concentration of the *C. occidentalis* pheromone (Cory and others 1982) would have no effect on the pheromone in adjacent traps with traps placed no closer than 100 ft to any neighbor.

EVALUATION OF DEPLOYMENT SYSTEM

The system described here has worked very well for us for several years. We usually leave the poles in the ground through fall, winter, and spring; even on steep terrain in areas of heavy snow we experience little damage. Moreover, our care in drilling the poles allows us to also leave the wires on the poles without loss during the winter.

Deer, elk, and bear have damaged some of the traps, but this would happen regardless of what type of trap or trap fixtures used. Animals occasionally rip the traps off the poles, but usually the hangers remain in place (though often bent out of shape) and there is never any damage to the poles. We experience no animal-caused damage during that period of the year when the traps are not attached to the poles.

In summary, this trap deployment system has been advantageous for us for at least four reasons:

1. The deployment method allows a systematic and gridded distribution of traps throughout our study areas.
2. The method allows reproducibility of sampling since on successive days or successive years traps are deployed at exactly the same place.
3. Since the traps are firmly affixed to the poles, and do not move about in the wind, we are able to measure directional catches.
4. We are able to control the height of the traps. This could be important for trapping some species of insects in regeneration plots, plantations, or nurseries.

PUBLICATIONS CITED

Cory, H. T.; Daterman, G. E.; Daves, G. D.; Sower, L. L.; Shepherd, R. F.; Sanders, C. J. Chemistry and field evaluation of the sex pheromone of the western spruce budworm, *Choristoneura occidentalis* Freeman. J. Chem. Ecol. 8(2): 339–350; 1982.

Daterman, G. E. Synthetic sex pheromone for detection survey of European pine shoot moth. Res. Pap. PNW–180. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 12 p.

Daterman, G. E. Monitoring and early detection. In: Brookes, M.; Stark, R. W.; Campbell, R. W., eds. The Douglas-fir tussock moth: a synthesis. Tech. Bull. 1585. Washington, DC: U.S. Department of Agriculture, Forest Service, Science and Education Agency; 1978: 99–102.

Daterman, G. E.; Livingston, R. L.; Wenz, J. M.; Sower, L. L. How to use pheromone traps to determine outbreak potential. Douglas-fir tussock moth handbook. Agric. Handb. 546. Washington, DC: U.S. Department of Agriculture; 1979. 11 p.

Liebhold, A. M.; Volney, W. Jan A. Effect of foliage proximity on attraction of *Choristoneura occidentalis* and *C. retinia* (Lepidoptera:Tortricidae) to pheromone sources. Paper presented at combined Entomol. Soc. Amer., Entomol. Soc. Canada, and Entomol. Soc. Ontario at Toronto, Ontario, Canada; 1982 December 2. (Manuscript in preparation to be submitted to J. Chem. Ecol.)

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U.S. GOVERNMENT PRINTING OFFICE: 1983—676-032/1012 REGION NO 8

A 13.79: INT- Research Note number 331
is missing from our collection and
cannot be obtained.

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-332

July 1983

Techniques for Implementing the Individual Tree Selection Method in the Grand Fir-Cedar-Hemlock Ecosystems of Northern Idaho

**Russell T. Graham
Richard A. Smith**[1]

ABSTRACT

Methodology in stands using the individual tree selection silviculture method includes selecting stands and desired diameter distributions, determining the cutting cycle, and marking the stands. However, some cautions should be heeded.

KEYWORDS: selection method, uneven-aged, diameter distributions

INTRODUCTION

The individual tree selection method has been used very little in the Northern Rocky Mountains. This method requires more planning and silviculturally is difficult to apply, more expensive, and more difficult to regulate than even-aged methods. Until recently, uneven-aged silviculture methods were not considered as management options in the grand fir-cedar-hemlock ecosystem. Now, because of demands for continuous cover on many sites, forest plans include many acres to be managed with uneven-aged methods, as has been done along stream courses and in viewing areas.

In grand fir-cedar-hemlock ecosystems, the individual-tree selection method will promote the regeneration and growth of shade-tolerant species such as western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), western redcedar (*Thuja plicata* Donn), grand fir (*Abies grandis* [Dougl.] Lindl.), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.). Douglas-fir (*Pseudotsuga menziesii* [Beissn.] Franco) and western white pine (*Pinus monticola* Dougl.) might be maintained in an uneven-aged condition depending on stand structure, residual basal area, and local site conditions.

Before considering application of the individual-tree selection method in northern Idaho, stand and site conditions as well as forest management goals should be carefully considered. The method will result in a stand with a far different structure and species mix than traditionally obtained and managed in northern Idaho.

STAND SELECTION

The foremost considerations in applying single-tree selection are the (1) present species mix and (2) present stand diameter (age) distribution. The method may be applied to any stand, but the conversion process is much simpler in stands that already tend to be multiaged. The stand should be of good vigor and not be highly defective. The stand may have a component of shade-intolerant species but should not be dominated by them because the regeneration in the stand will have to occur in shaded or partially shaded conditions.

---

[1] Research forester, Intermountain Forest and Range Experiment Station, located at Forestry Sciences Laboratory, Moscow, Idaho, and forester, Idaho Panhandle National Forest, respectively.

RESIDUAL BASAL AREA

A residual basal area should be chosen that will allow good stand growth but keep the site well occupied. In northern Idaho this level could range from 60 ft²/acre to 175 ft²/acre (13.8 m²/ha to 40.2 m²/ha), depending on the site and species mix. In the absence of better information, even-aged yield tables (Haig 1932), stocking levels by habitat types (Pfister and others 1977), or other similar information may be used to estimate this level.

MAXIMUM TREE SIZE

A maximum tree size should be selected as a goal for the stand. Depending on management objectives, the maximum is usually medium-sized sawtimber ranging from 18 to 26 inches (46 to 66 cm) in diameter. Any size can be chosen, but this range is applicable for most sites in northern Idaho.

DIAMETER DISTRIBUTION

A balanced size class distribution is intended to provide (1) good conditions for growth and quality development, (2) sustained yield, and (3) maximum yield where harvest equals growth (Tubbs and Oberg 1978). The most commonly used method to develop a balanced size class distribution is to use a geometric progression, which is described by the ratio between the number of trees in succeeding size classes. This ratio is referred to as q or de Liocourt's q. The number of trees in a size class multiplied by q results in the number in the next smaller size class.

Presently no information is available on what diameter distributions should be used in the grand fir-cedar-hemlock ecosystem. Therefore, a diameter distribution approaching the natural distribution is a good approximation. If management goals indicate a high proportion of large trees is desired, diameter distributions described by low q's (1.1) may be preferred. Large q's describe stands with many small trees. With our limited experience with uneven-aged silviculture in the grand fir-cedar-hemlock stands of northern Idaho, q's of 1.1 to 1.5 appear to work well.

STAND STRUCTURE

Several ways exist to calculate the desired diameter distribution based on residual basal area, maximum tree size, and q's, but Tubbs and Oberg (1978) present the simplest method. They developed a coefficient for 2-inch (5-cm) diameter classes called a K factor, which depends on the desired q and maximum tree size (table 1).

Table 1.—K-coefficient for a given maximum diameter and q-factor

Maximum diameter	q-factor						
	1.1	1.2	1.3	1.4	1.5	1.6	1.7
24	18.5	24.8	34.3	48.1	68.0	97.3	139.3
22	14.0	18.2	24.0	32.1	43.4	58.9	80.1
20	10.3	13.0	16.4	21.1	27.2	35.2	45.6
18	7.4	9.0	11.0	13.5	16.7	20.6	25.5

From: Tubbs and Oberg 1978.

The desired residual basal area is divided by the k factor to get the number of trees in the largest 2-inch (5-cm) diameter class (N). N is then multiplied by the applicable q to find the number of trees in the next smaller size class, which in turn is multiplied by the q to find the number of trees in the next smaller size class, and so on to the smallest class. For example:

q-factor: 1.2
Residual basal area: 120 ft²/acre
Maximum tree size: 24 inches.

Therefore:

K-factor: 24.8
N = 4.84 for the 24-inch class
N = 5.81 for the 22-inch class
N = 6.97 for the 20-inch class
.
.
.
N = 35.96 for the 2-inch class.

This procedure results in a diameter distribution curve that is a reverse J shape (fig. 1). The actual stand diameter distribution can be plotted on the same graph resulting in figure 2. From the comparison of the actual stand to the desired stand, we can estimate the number of trees that can be removed from each diameter class:

Diameter class	Excess trees/acre
12	8
14	7
20	3
22	4
24	5

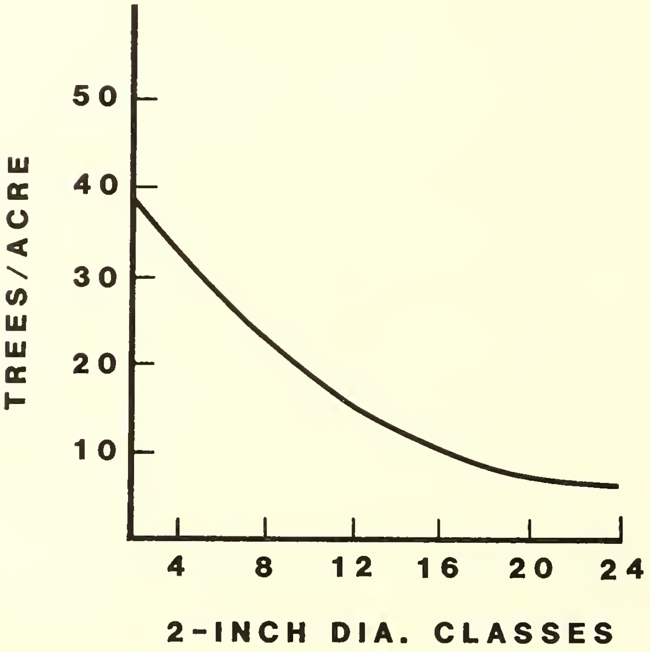


Figure 1.—Desired stand structure.

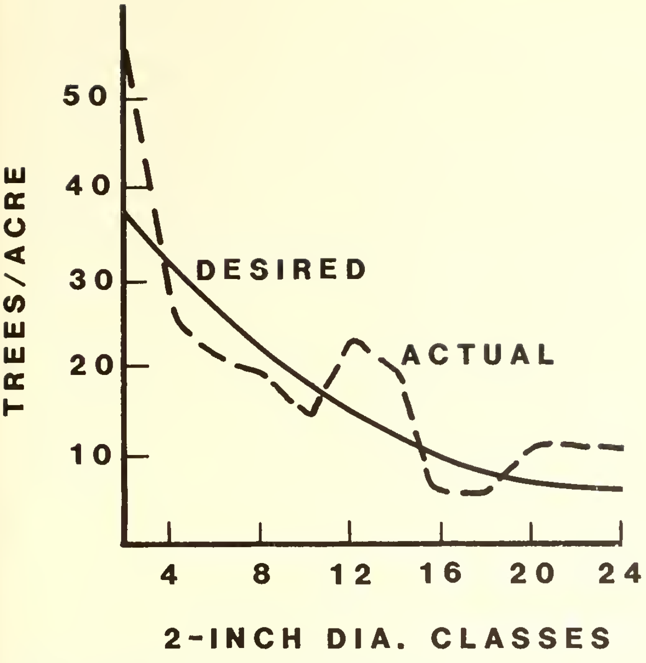


Figure 2.—Desired and actual stand structure.

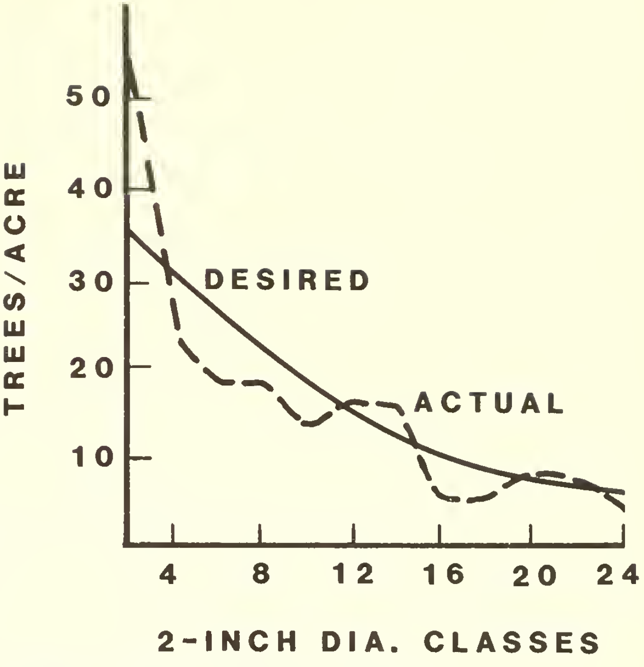


Figure 3.—Desired and actual stand structure after marking.

CUTTING CYCLE

The determination of the cutting cycle will depend on projected stand growth and when a commercial entry could again be made in the stand. For most sites in the grand fir-cedar-hemlock ecosystems of northern Idaho, 500 to 700 bd.ft./acre/year can be realized resulting in a harvestable volume of over 5,000 bd.ft./acre on a 10-year cutting cycle. Even-aged yield tables (Haig 1932), stand projection systems (Stage 1973), and vegetation classification systems (Pfister and others 1977) could help make a proper decision on cutting-cycle length.

STAND MARKING

Two- to three-person crews work best in marking stands using the individual-tree selection method. The crew size allows for easy communication.

The first consideration is the residual basal area. At any point in the stand, an angle gage check of the basal area left after marking should approach that desired. If the basal area exceeds the desired level, additional trees from the cut list should be marked for removal to reduce the basal area to the desired level. Also, a tally of the total cut-trees will prevent exceeding the total number of trees from the cut list for the entire stand. Depending on the stand size and structure, it may be desirable to work with diameter classes larger than 2 inches (5 cm).

Tree selection for cutting should be based on vigor, form, and so forth, as in any stand marking procedure. Also, trees of poor health that will not survive to the next cutting cycle should be removed, being careful not to deviate far from the desired stand structure. It is often difficult to mark stands using uneven-aged methods when the personnel are accustomed to marking shelterwood and seed tree units. After marking the stand, graphic structure should resemble that desired (fig. 3).

CAUTIONS

The individual-tree selection method is difficult to apply, and little information is available on yields, conversion problems, logging systems, sampling problems, and disease and insect consequences. Also, the method will promote the regeneration and growth of shade-tolerant species that are slower growing and less valuable than shade-intolerant species. Therefore, until more application information is available, care should be taken to apply the method where there is a high probability of success. Do not, for any reason, try to apply it in stands that are of poor vigor, or where the diameter distribution is not conducive to conversion to an all-aged structure.

PUBLICATIONS CITED

Haig, I. T. Second-growth yield, stand, and volume tables for the western white pine type. Tech. Bull. 323. Washington, DC: U.S. Department of Agriculture; 1932. 67 p.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Stage, A. R. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Tubbs, C. H.; Oberg, R. R. How to calculate size-class distribution for all-aged forests. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1978. 5 p.

OTHER REFERENCES

Alexander, R. R.; Edminster, C. B. Uneven-aged management of old growth spruce-fir forests: cutting methods and stand structure goals for the initial entry. Res. Pap. RM-186. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 12 p.

Alexander, R. R.; Edminster, C. B. Regulation and control of cut under uneven-aged management. Res. Pap. RM-182. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 7 p.

Frank, Robert M.; Bluc, Barton M. The selection system of silviculture in spruce-fir stands—procedures, early results, and comparisons with unmanaged stands. Res. Pap. NE-425. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1978. 15 p.

Hann, P. W.; Bare, B. Uneven-aged forest management: state of the art (or science?). Gen. Tech. Rep. INT-50. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 18 p.

Murphy, P. A.; Farrar, R. M. Stand structure variability and research plot size in uneven-aged stands of loblolly-shortleaf pine. Res. Pap. SO-171. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1981. 3 p.

U.S. Department of Agriculture, Forest Service. Uneven-aged silviculture and management in the United States. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management Research; 1978. 234 p.

U.S. GOVERNMENT PRINTING OFFICE: 1983—676-032/1022 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-333

July 1983

Harvesting Strategies for Management of Mountain Pine Beetle Infestations in Lodgepole Pine:

Preliminary Evaluation, East Long Creek Demonstration Area, Shoshone National Forest, Wyoming

**Walter E. Cole,[1] Donn B. Cahill,[2]
and Gene D. Lessard[3]**

ABSTRACT

Diameter-limit and leave-tree cuts were tested as ways to reduce or minimize lodgepole pine losses to the mountain pine beetle. In the first year after treatment, loss reductions were proportional to the intensity of cut. According to the Rate of Loss Model, the 100-leave-tree cut was the best deterrent of recurring infestation, measured as amount of losses and length of time. The 100-leave-tree cut also should provide the best regeneration and has the added benefit of reducing dwarf mistletoe infection.

KEYWORDS: mountain pine beetle, *Dendroctonus ponderosae,* lodgepole pine, *Pinus contorta* var. *latifolia,* harvest strategies

East Long Creek in the Shoshone National Forest is one of a series of demonstration area projects that used management alternatives derived from research (Cole and Cahill 1976) and small-scale tests (Cahill 1978; McGregor and Cole, in press) in an attempt to reduce or minimize lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) losses to the mountain pine beetle (*Dendroctonus ponderosae* Hopkins).

The objective of this initial large-scale application of management alternatives was to prevent undue losses of lodgepole pine by changing or reducing the food supply of the mountain pine beetle, and also to manipulate the stand to grow at or near optimum site capacity with continued prevention of large losses to the beetle.

Some constraints on the project were to protect or enhance key resource values, remove merchantable material through a commercial timber sale, develop permanent access roads for general land use and management, improve forest cover growing conditions through disease control and stocking to attain timber production potentials on regulated lands, and develop a cost-benefit analysis for each strategy. This report is limited to the reaction of the mountain pine beetle and tree growth response the first year after cutting.

Future efforts to manage stands to prevent losses to the beetle must be made before the beetle epidemic cycle. East Long Creek Demonstration Area provided this opportunity.

---

[1] Principal Entomologist, Population Dynamics of the Mountain Pine Beetle Research Work Unit, Intermountain Forest and Range Experiment Station, Ogden, Utah.

[2] CANUSA Entomologist, Forest Pest Management, Boise Zone Office, Intermountain Region, USDA Forest Service, Boise, Idaho.

[3] Entomologist, Forest Pest Management, Rocky Mountain Region, USDA Forest Service, Lakewood, Colo.

STUDY AREA

The East Long Creek Demonstration Area lies between 7,600 and 8,800 ft (2 317 and 2 683 m) elevation, which is the lower half of the forested zone in the Wind River Drainage. The climate is cool and dry; moisture availability is the most limiting growth factor during the season.

Soils are derived from sedimentary formations and glacial moraines derived from the Wiggins formation. The clay content of the soils and seasonal distribution of precipitation make natural regeneration difficult on southerly and westerly aspects and flats, especially below 8,500 ft (2 591 m).

Cover types change with aspect and elevation; coniferous trees grow only on favorable aspects below 7,600 ft (2 317 m), and seldom occur on more adverse aspects at higher elevations.

Reestablishment of conifers following fire is extremely slow on adverse aspects. Recovery from any drastic disturbance on this area can be expected to be slow unless seedlings are planted as the regeneration method. On some of the adverse aspects, the scattered limber pine (*P. flexilis* James) and lodgepole pine trees appear to be pioneers of a first generation forest.

The lower part of the coniferous cover could be classed as *Abies lasiocarpa-Arnica cordifolia* habitat type, milk vetch phase. This habitat type on the Wind River District has almost no potential to be dominated by *Abies lasiocarpa* because the development of the climax community requires more time than is permitted by the natural fire cycle.

Inland Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) predominates in an alternative seral community on this habitat type where soils are basic. At this elevation, the inland Douglas-fir/mountain snowberry habitat is present on soils derived from limestone formations.

Aspen (*Populus tremuloides* Michx.) is a short-lived seral community replaced by limber pine or lodgepole pine in the first generation. Retention of aspen as a cover type requires a reduction in competition for moisture and cutting the live aspen to break the auxin flow so sprouting can occur.

In most of the stands in this zone, the lodgepole pine component of the stand is 150 to 200 years old and dying out rapidly. Younger stands are still dominated by lodgepole pine and have a manageable pole and small-size sawtimber component. This zone of the coniferous forest is an *Abies lasiocarpa-Vaccinium scoparium* habitat type.

Regeneration following disturbance is more rapid in this habitat and will tend to be mixed aged, with some tolerant species seedlings and saplings present in the first 50 years of stand development. The number of spruce and fir trees present during early stand development probably depends on seed source, once the lodgepole pine component accomplishes the necessary site modification. In some cases, competition by density stocked lodgepole pine may reduce spruce and fir regeneration.

Site index values for lodgepole pine are 30 to 35 ft (9.1 to 10.7 m) in 50 years in the *Abies lasiocarpa-Arnica cordifolia*-milk vetch phase habitat, increasing to 45 to 50 ft (13.7 to 15.2 m) in 50 years in the *Abies lasiocarpa-Vaccinium scoparium* habitats.

Throughout this area of the forest, basal area in natural stands follows the site index values, with basal areas as low as 65 ft^2/acre (14 .4 m^2/ha) on the lower site index areas and increasing to 140 ft^2/acre (31.1 m^2/ha) on the most productive sites. Total live conifer trees over 2 inches (5.08 cm diameter at breast height) (d.b.h.) on the 1,789 acres (724 ha) cruised rarely exceeded 400 per acre (988 per ha).

The demonstration area contained approximately 1,898 acres (768 ha). Before harvesting, the area contained 3,777 board feet (bd.ft.) of gross green volume per acre and 1,664 bd.ft. of dead standing volume per acre. Net volumes were 3,397 bd.ft. of green volume per acre and 1,332 bd.ft. of dead volume per acre, or 4,729 bd.ft. total net volume per acre.

STAND PRESCRIPTIONS

Three general prescriptions were applied: (1) cutting levels based on diameters, (2) leave-tree cuts, and (3) clearcuts. In each case, the primary purpose was to remove the food supply from the beetle; the larger diameter trees generally contain the thicker phloem. However, other criteria were considered in each case. Each prescription required retention of adequate forest cover to promote natural regeneration, wildlife needs, and visual qualities, and was designed to fit the condition of the stand and its ecology to promote future development under natural conditions.

The prescriptions and their applications were:

1. Diameter cuts.
    a. Cut all lodgepole pine 7 inches (17.78 cm) d.b.h. and larger and salvage dead trees 8 inches (20.32 cm) d.b.h. and larger. This prescription was applied to three different stand conditions:
        (1) Late transitional stands that had converted to the spruce-fir type. The lodgepole pine component was decadent or dying rapidly. In this case, adequate lodgepole pine growing stock was to be retained. Lodgepole pine regeneration could be expected to fill in openings created by logging.
        (2) Two-aged lodgepole pine stands that contained very few tolerant trees. The understory was primarily lodgepole pine, and the residual stand of seedlings and saplings would be understocked. Trees less than 7 inches (17.78 cm) d.b.h. down to the seedling-sapling understory were not suitable growing stock because of disease—dwarf mistletoe (*Arceuthobium americanum*) and comandra blister rust (*Cronartium comandrae*). It was necessary on these sites to retain the undesirable pole timber to protect the site until natural regeneration occurs to bring the seedling-sapling stand up to 300 per acre (121 per ha). Timely removal of mistletoe-infected trees will be required.

In some cases where stocking was inadequate and residual trees were sparse—less than 100 per acre (40 per ha)—planting would be necessary. Lodgepole pine or inland Douglas-fir containerized stock should be planted at 200 to 400 trees per acre (81 to 162 per ha) depending on the number and size of residual growing stock trees.

(3) Heavily stocked lodgepole pine pole timber stands where the age and disease conditions made regeneration of the stand desirable, and enough trees less than 7 inches (17.78 cm) d.b.h. were present to furnish adequate cover to meet forest cover objectives, including site protection. Adequate natural regeneration was expected in these stands.

b. Cut all lodgepole pine trees 10 inches (25.40 cm) d.b.h. and larger and salvage all dead or attacked trees 8 inches (20.32 cm) d.b.h. and larger. This prescription was applied to isolated stands in the unthinned component where forest cover was not maintained for production of wood products, but primarily where lodgepole pine was the principal component and cover objectives required retaining forest cover to protect other values.

Site potential was low in these stands, ecosystems were exceptionally fragile, and values other than timber were paramount. The prescription was applied to stands that were sparsely stocked and on adverse aspects. These stands were suspected to be first-generation coniferous forests, hence were fragile ecotones, and disruption could reverse ecologic trends. Subsequent treatments on regulated lands will be overstory removal in one or two steps, depending on disease conditions, regeneration success, and visual quality needs.

c. Cut all lodgepole pine trees 12 inches (30.48 cm) d.b.h. and larger and salvage all dead or attacked trees 8 inches (20.32 cm) and larger. This prescription was applied to stands where lodgepole pine was the principal component, site potential was extremely low, stands were sparsely stocked, aspects were adverse, and stands contained trees exceeding this diameter limit.

2. Leave-tree cuts.

The leave-tree prescription was applied to two stands and required leaving 100 trees per acre (40 trees per ha), while removing the balance of the lodgepole pine component of the stand. All selected leave trees were the largest, most desirable lodgepole pine, growing stock, and sufficient desirable growing stock trees of other species were retained to result in an average stocking of 100 trees per acre (40 per ha) over 7 inches (17.78 cm) d.b.h.

Because of small islands of old lodgepole pine that escaped the fire that regenerated these two stands, and because these stands contained mistletoe infection centers, small clearcuts also were required. Natural regeneration could be expected in 5 years if these clearcuts did not exceed 5 acres (2 ha).

3. Clearcuts.

Six areas, averaging 14 acres (5.7 ha) each, were clearcut. These were in fire-regenerated pole timber stands. There were small islands of old-aged, larger diameter lodgepole pine trees that were diseased and decadent. Some of these islands had lodgepole pine and/or spruce-fir understories. Because of the heavy fuel accumulations in the pockets of old growth, bulldozer piling and slash burning were desirable to meet fuel management objectives.

METHODS

A total of 37 cutting units and one check block unit were laid out in the demonstration area:

10 units in the 7-inch (17.78-cm) cutting block
17 units in the 10-inch (25.40-cm) cutting block
2 units in the 12-inch (30.48-cm) cutting block
2 units in the 100-leave-tree cutting block
6 units in the clearcut block
1 check block unit

Harvesting began in January 1979 and was completed in February 1981, well before the 1981 beetle flight. A summary of the pretreatment stand structure and proposed cuts is shown in table 1.

A survey of the demonstration area was made in the spring of 1982 to determine tree loss to the mountain pine beetle. A 20-percent survey was conducted in 22 of the 38 units:

6 of 10 units in the 7-inch (17.78-cm) cutting block
11 of 27 units in the 10-inch (25.40-cm) cutting block
2 of 2 units in the 12-inch (30.48-cm) cutting block
2 of 2 units in the 100-leave-tree block
1 check block unit

The 20-percent survey used a 1-chain-wide strip (20 m) every 5 chains (100 m) and recorded beetle-killed trees in 1979, 1980, and 1981, other causes of death, and diameter.

Tree growth data were collected during the loss surveys. Basal area and radial growth measurements were taken at 5-chain (100 m) intervals along the cruise strip, using a 10 BAF gage. Unfortunately, similar data were not taken before the harvest for comparison.

Table 1.—Summary of stand data and proposed cuts for East Long Creek Demonstration Area

	Treatment				
Stand structure and volumes	**7-inch**	**10-inch**	**12-inch**	**100-leave-tree**	**Clearcut**
Acres					
Total	1,132.0	581.0	60.0	39.0	86.0
Mean	113.2	34.2	30.0	19.5	14.3
Live lodgepole/acre					
Total	1,633.0	3,668.0	686.0	428.0	1,475.0
Mean	163.3	215.7	343.0	214.0	245.8
< 7-inch	864.0	1,925.0	458.0	242.0	769.0
Mean	86.4	113.2	229.0	121.0	128.2
> 7-inch	769.0	1,743.0	228.0	186.0	706.0
Mean	76.9	102.5	114.0	93.0	117.7
> 10-inch	352.0	656.0	88.0	62.0	271.0
Mean	35.2	38.6	44.0	31.0	45.2
>12-inch	166.0	282.0	14.0	24.0	156.0
Mean	16.6	16.6	7.0	12.0	26.0
Live species/acre					
Subalpine fir and other	768.0	699.0	66.0	30.0	1,006.0
Mean	76.8	41.1	33.0	15.0	167.7
Engelmann spruce	194.0	47.2	0	2.4	248.0
Mean	19.4	2.8	0	1.2	41.3
Aspen	1,683.0	232.0	0	64.0	34.0
Mean	168.3	13.6	0	32.0	5.7
Proposed cut					
T/A	769.0	656.0	14.0	228.0	1,475.0
Mean	76.9	38.6	7.0	114.0	245.8
Gross volume/acre					
Live cut	4,468.0	3,518.0	3,683.0	3,205.0	4,093.0
Mean	4,468.0	3,518.0	3,683.0	3,205.0	4,093.0
Salvage cut	2,290.0	1,480.0	1,583.0	1,231.0	2,337.0
Mean	2,290.0	1,480.0	1,583.0	1,231.0	2,337.0
Gross volume (M)					
Green	5,058.0	2,044.0	221.0	125.0	352.0
Mean	505.8	120.2	110.5	62.5	58.7
Dead (≥8″)	2,592.0	860.0	95.0	48.0	201.0
Mean	259.2	50.6	47.5	24.0	33.5
Uncut per acre					
Lodgepole pine (≥2″)	891.0	2,916.0	558.0	39.0	877.0
Mean	89.1	171.5	279.0	19.5	146.2
Total trees (≥2″)	1,602.0	3,661.0	624.0	43.0	2,132.0
Mean	160.2	215.4	312.0	21.5	355.3
Average gross volume per acre (M)					
Green	4.468	3.518	3.683	3.205	4.093
Dead	2.290	1.480	1.583	1.231	2.337
Average net volume per acre (M)					
Green	4.023	3.166	3.315	2.885	3.684
Dead	1.832	1.184	1.267	.985	1.870
Total adjusted net volume					
Volume per acre	5.855	4.350	4.582	3.870	5.554
Net volume	6.628	2.528	.275	.151	.478

RESULTS

The stand structure changed proportionally to the intensity of harvest cut used in each block (table 2). Stand average diameter (d.b.h.) changes were:

Treatment	Original diameter		Diameter after harvest	
	Inches	*cm*	*Inches*	*cm*
7-inch (17.78-cm) cut	7.8	19.81	7.0	17.78
10-inch (25.40-cm) cut	7.7	19.56	7.0	17.78
12-inch (30.48-cm) cut	7.4	18.80	7.3	18.54
100-leave-tree cut	7.5	19.05	8.0	20.32

Considering only the kill by the mountain pine beetle, the trend for the 3 years (2 years before the cut was completed and 1 year after completed cuts) is rather dramatic (table 3 and fig. 1). In all cutting blocks, the number of trees infested dropped considerably after harvesting; the check block continued to lose trees to the beetle at about the same rate.

It is evident that tree loss to secondary insects, such as *Ips*, *Pityophthorus*, *Pityogenes*, and *Pityokteines*, and comandra rust lessened after treatment (table 4). However, this apparent reduction of loss may be an artificial effect of sampling, because the check areas also showed no loss due to these factors in 1981 (the year after cutting was completed).

Table 2.—Stand structure before and after cutting

Treatment	Live lodgepole pine per acre by diameter class										
	Before cut					Trees cut per acre	After cut				
	Total	<7 inches	7-9 inches	10-11 inches	>12 inches		Total	<7 inches	7-9 inches	10-11 inches	>12 inches
7-inch cut	163.3	86.4	41.7	18.6	16.6	76.9	86.4	86.4	0	0	0
10-inch cut	215.7	113.2	63.9	22.0	16.6	38.6	177.1	113.2	63.9	0	0
12-inch cut	343.0	229.0	70.0	37.0	7.0	7.0	336.0	229.0	70.0	37.0	0
100-leave-tree cut	214.0	121.0	62.0	19.0	12.0	114.0	[1]100.0	—	—	—	—
Clearcut	245.8	128.2	72.5	19.2	26.0	245.0	0	0	9	0	0
Check area	251.0	[2]55.0	196.0	91.0	42.0	0	251.0	[2]55.0	196.0	91.0	42

[1] Data not available on distribution.

[2] Include only 4- to 6-inch trees.

Table 3.—Tree mortality due to the mountain pine beetle

Treatment	Number of trees killed per acre			
	1979	1980		1981
7-inch cut	0.72	0.51	cut completed	0.09
10-inch cut	.35	.66		.07
12-inch cut	.19	5.00		1.15
100-leave-tree cut	.20	.10		0
Check area	2.53	5.77		4.23

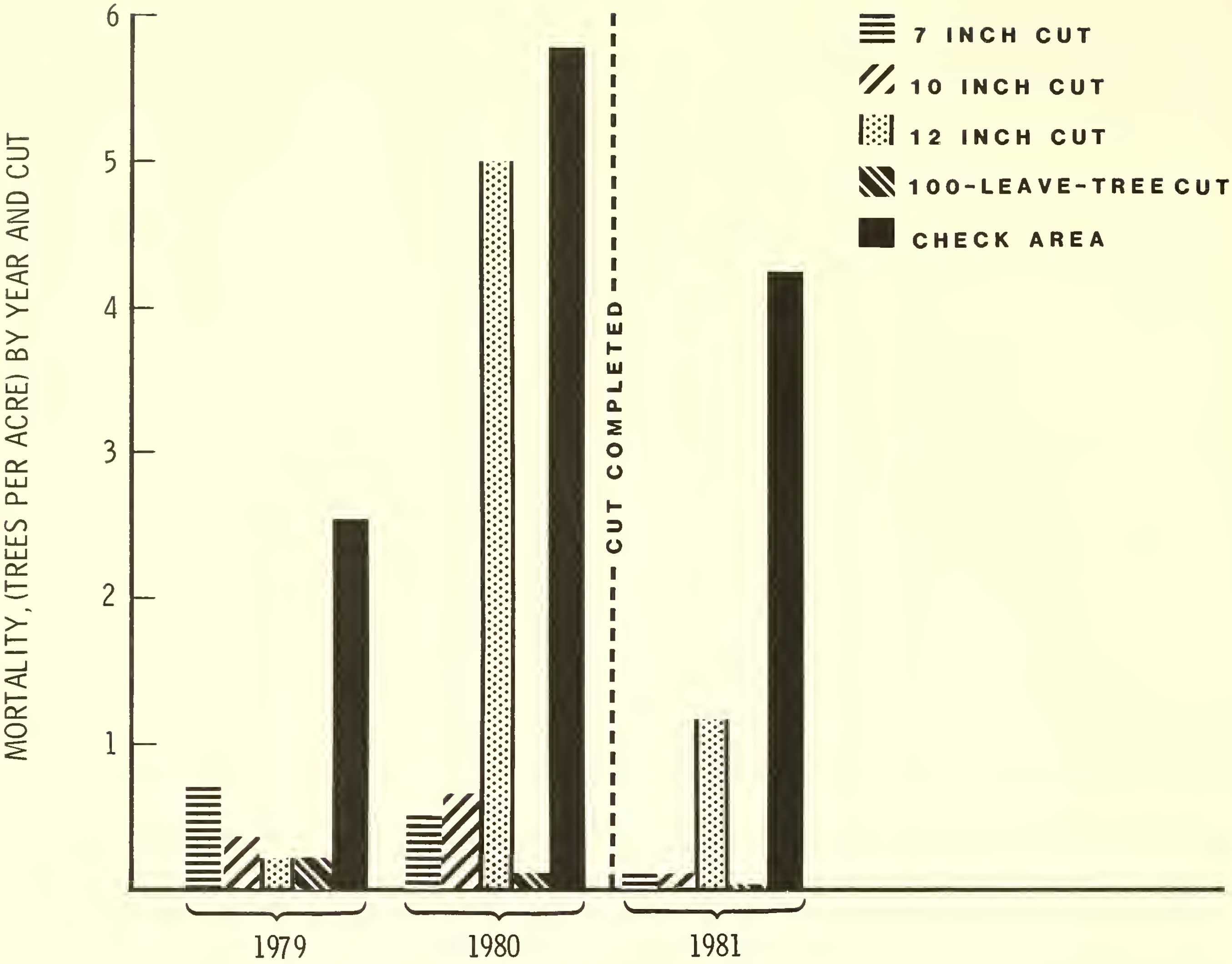


Figure 1.—Tree loss due to the mountain beetle within the demonstration areas.

Table 4.—Trees killed per acre by cutting block, year, cause, and diameter

Treatment	Year of kill	Cause of death	Diameter of tree killed (inches)												Total trees killed	Trees killed per acre
			6	7	8	9	10	11	12	13	14	15	16	>17		
7-inch cut	1979	MPB[1]	2	3	3	3	7	4	1	1					24	0.72
		Pity's[2]	1		1	1									3	.09
		Total		3	3	4	4	7	4	1	1				27	.81
	1980	MPB		2	3	5	1	2	3	1					17	.51
		Pity's			1	1									2	.06
		Comandra	1												1	.03
		Total	1	2	4	6	1	2	3	1					20	.60
	1981	MPB								1			1	1	3	.09
		Total								1			1	1	3	.09
	All years		4	5	8	10	8	6	4	3			1	1	50	1.51
10-inch cut	1979	MPB	1	2	2	10	2	2							21	.35
		Ips spp.	1	3	2										6	.10
		Pity's	6	8	3	5									22	.36
		Comandra		1	1										2	.03
		Total	8	15	9	15	2	2							51	.84
	1980	MPB	1	6	12	9	4	3	2	1	1			1	40	.66
		Pity's	4	3	4	1									12	.20
		Comandra		2	2	1									5	.08
		Total	5	11	18	11	4	3	2	1	1			1	57	.94
	1981	MPB			1	1	1						1		4	.07
		Total			1	1	1						1		4	.07
	All years		13	26	28	27	7	5	2	1	1		1	1	112	1.78
12-inch cut	1979	MPB											1		1	.19
		Comandra	2		1		1						1		4	.77
		Total	2		1		1						1		5	.96
	1980	MPB	1	1	4	5	5	7	3						26	5.00
		Pity's					1								1	.19
		Comandra		1									1		1	.19
		Total	1	2	4	5	6	7	3						28	5.38
	1981	MPB		1	2			3							6	1.15
		Total		1	2			3							6	1.15
	All years		3	3	7	5	7	10	3				1		39	7.50
100-leave tree cut	1979	MPB	1		1										2	.20
		Ips spp.	1			1		1							3	.30
		Total	2		1	1		1							5	.50
	1980	MPB		1											1	.10
		Ips spp.	1	1											2	.20
		Total	1	2											3	.30
	1981	MPB	1												1	.10
		Total	1												1	.10
	All years		4	2	1	1			1						9	.90
Check area	1979	MPB		4		9	5	9	1	5	1	1			36	2.53
		Pity's		3											3	.21
		Total		4	3	9	5	9	1	5	1	1			39	2.74
	1980	MPB	1	1	4	11	14	18	10	8	6	1	2	6	82	5.77
		Pity's				1									1	.07
		Comandra					1								1	.07
		Total	1	1	4	12	15	18	10	8	6	1	2	6	84	5.91
	1981	MPB			6	5	9	11	13	6	5		4	1	60	4.23
		Total			6	5	9	11	13	6	5		4	1	60	4.23
	All years		1	5	13	26	29	38	24	19	12	2	6	7	183	12.88

---

[1] MPB = Mountain pine beetle.

[2] *Pityophthorus*, *Pityogenes*, and *Pityokteines*.

Adding the loss due to the mountain pine beetle, secondary insects, and comandra rust to the trees cut per acre gives the gross number of trees removed and thus the residual trees per acre (table 5). All cutting blocks now contain almost the same number of trees per acre, which is about one-half the number per acre now in the check area, although the average stand diameter is different.

Residual basal area followed the level of cut as would be expected (fig. 2). Using the check blocks as a base, then 66 percent of the basal area was removed in the 7-inch (17.78-cm) blocks; 55 percent in the 10-inch (25.40-cm) blocks; 45 percent in the 12-inch (30.48-cm) blocks; and 63 percent in the 100-leave-tree blocks.

There was an apparent and slightly greater radial growth, of those residual trees measured, in the 12-inch (30.48-cm), 100-leave-tree, and check blocks as compared to the 7-inch (17.78-cm) and 10-inch (25.40-cm) blocks (fig. 3). This does not necessarily reflect release by cutting, because only 1 to 2 years of growth occurred since cutting was started.

Table 5.—Net effects to the stands from cutting levels and mortality factors

Treatment	Trees per acre						
	Before cut	Number cut	Trees Killed by				Residual
			MPB[1]	*Ips* spp.	Pity's[2]	Comandra	
7-inch cut	163.3	76.9	1.32	0	0.15	0.03	84.90
10-inch cut	215.7	113.2	11.08	0.10	.56	.11	90.76
12-inch cut	343.0	229.0	6.34	0	.19	.96	88.66
100-leave-tree cut	214.0	114.0	.30	.60	50	0	99.70
Check area	196.0	0	12.53	0	.28	.07	183.12

[1] MPB = Mountain pine beetle.

[2] *Pityophthorus*, *Pityogenes*, and *Pityokteines*.

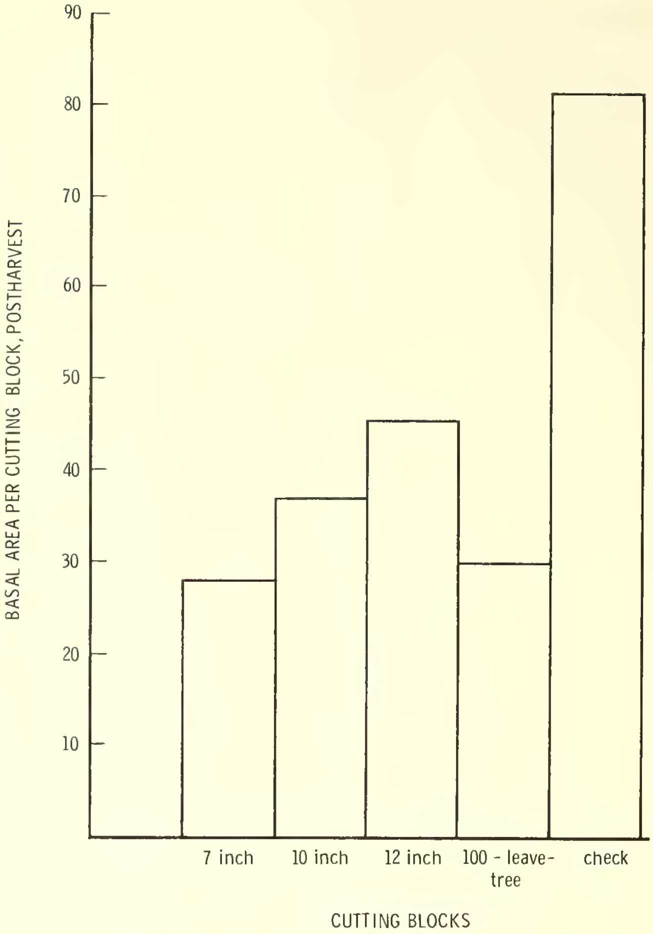


Figure 2.—Residual basal area of cutting blocks.

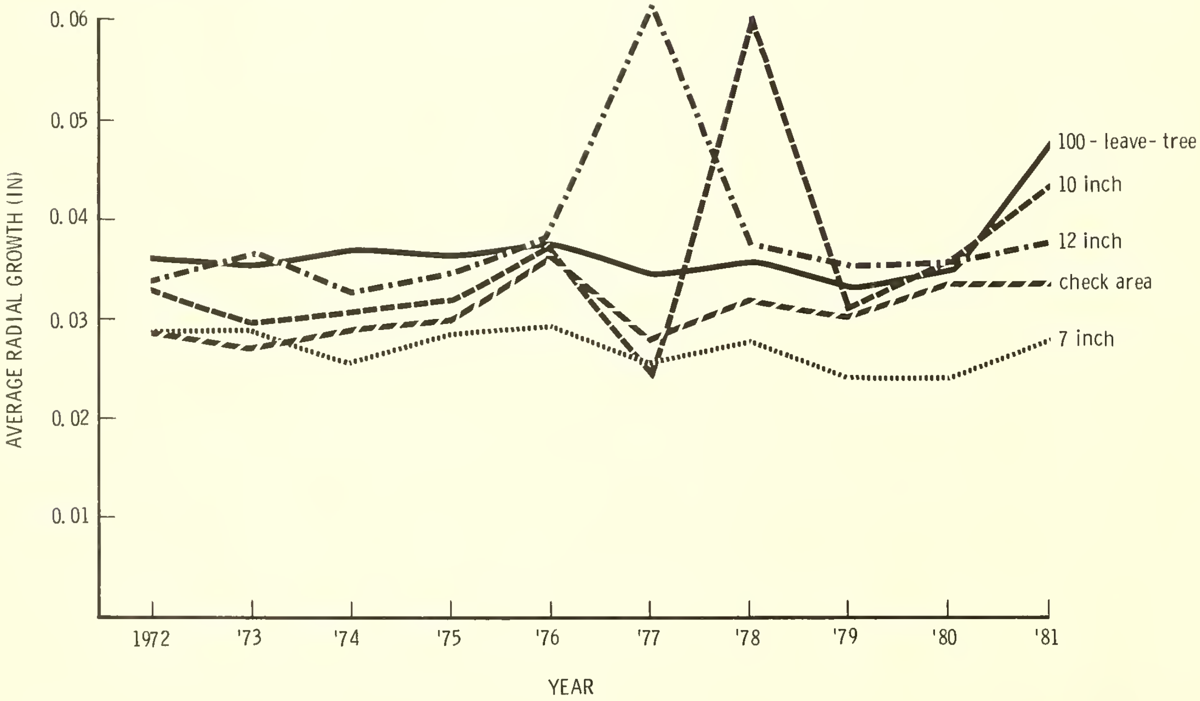


Figure 3.—Average radial growth of stand per year for last 10 years by cutting block.

DISCUSSION

Having seen the immediate results of the cutting levels, the question now is of the future of these stands, with respect to the activity of the beetle and stand development. The harvest levels reduced the current level of loss somewhat proportionally, but will the beetle resume killing trees at the same ratio as before treatment or has a change been induced in the course of the infestation? To project an answer to this question, these mortality trend data were used in the Rate of Loss Model (Cole and McGregor, in press) to predict the rate of future tree loss and number of years of such an infestation (fig. 4).

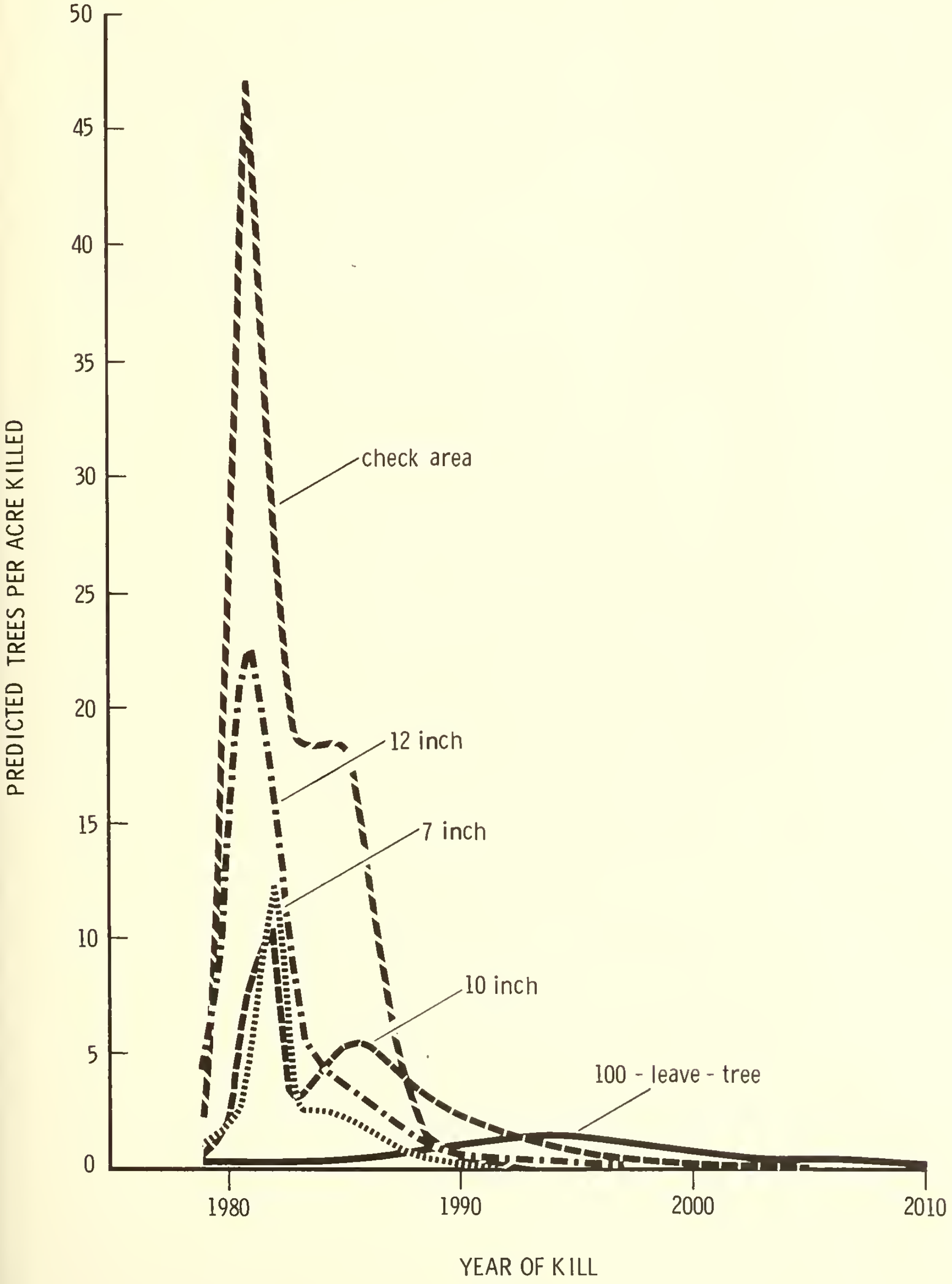


Figure 4.—Predicted trees per acre killed by mountain pine beetle, postharvest by cutting levels.

This projection showed that the infestation within the check area should peak in 1981, with 46.9 trees killed per acre (19 per ha), and subside to 1.1 trees per acre (0.44 per ha) by 1989, tailing to 0.02 tree per acre (0.008 per ha) by 1993. The diameter-limit cuts reduced the peak loss rather proportionally to the extent of cutting; for example, peak kill was greater in the 12-inch (30.48-cm) cuts than in the 7-inch (17.78-cm) cuts. The expected length of infestation changed accordingly, with the longest period of outbreak expected for the 7-inch (17.78-cm) cut. The exception was the 100-leave-tree cut. This cut extended the predicted life of the infestation to the year 2012, with peak tree loss of only 1.5 trees per acre (0.61 per ha) in the year 1993 (table 6).

Table 6.—Predicted peak loss, length of infestation, and annual drain from the mountain pine beetle by cutting level (trees per acre)

Treatment	Peak loss	Peak year	Years of infestation	Total loss	Annual drain
Check area	46.9	1981	14	180.5	12.9
12-inch cut	22.1	1981	18	80.1	4.4
10-inch cut	10.3	1982	26	62.5	2.4
7-inch cut	12.3	1982	13	32.8	2.5
100-leave-tree cut	1.5	1993	33	23.6	.7

The 100-leave-tree cut, according to these predictions, would reduce tree loss from the mountain pine beetle to a low amount. This cut would also be advantageous in reducing or minimizing dwarf mistletoe occurrence (Wicker 1967; Wicker and Shaw 1967). Once the area is reseeded and the regeneration height exceeds snow depth, the leave trees should be removed. The small target area of the regeneration, the washing action of the snow in removing dwarf mistletoe seeds, and the young stand being immune to the mountain pine beetle may well be the keys to producing a healthy new stand of lodgepole pine.

SUMMARY

The demonstration area on which diameter-limit and leave-tree cuts were applied to reduce or minimize lodgepole pine losses to the mountain pine beetle was evaluated the first year after cutting. First-year losses were reduced proportionally to the intensity of cut. Projected losses and continuation of the mountain pine beetle infestation were derived from the predictive Rate of Loss Model. The best deterrent of recurring infestation—amount of losses and length of time—was the 100-leave-tree cut. The 100-leave-tree cut also was the best in encouraging regeneration and reducing dwarf mistletoe infection.

PUBLICATIONS CITED

Cahill, Donn B. Cutting strategies as control measures of the mountain pine beetle in lodgepole pine in Colorado. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 188-191.

Cole, Walter E.; Cahill, Donn B. Cutting strategies can reduce probabilities of mountain pine beetle epidemics in lodgepole pine. J. For. 74: 294-297; 1976.

Cole, Walter E.; McGregor, Mark D. Estimating the rate and amount of tree loss from a mountain pine beetle infestation. In press.

McGregor, Mark D.; Cole, Walter E. Harvesting strategies for management of mountain pine beetle infestations in lodgepole pine. In press.

Wicker, Ed F. Seed destiny as a klendusic factor of infection and its impact upon propagation of *Arceuthobium* spp. Phytopathology. 57(11): 1164-1168; 1967.

Wicker, Ed F.; Shaw, C. Gardner. Target area as a klendusic factor in dwarf mistletoe infections. Phytopathology. 57(11): 1161-1163; 1967.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—676-032/1021 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-334

September 1983

Broadcast Seeding Success in Eight Pinyon-Juniper Stands After Wildfire

Susan Koniak[1]

ABSTRACT

Eight burns ranging from 1 to 18 years old in pinyon-juniper woodlands were examined to determine trends in establishment and survival of broadcast-seeded grass. The early plant communities following wildfire on low-elevation sites were dominated by annual forbs. Seeded grasses were present in small quantities on most sites, with highest occurrence on north slopes. On older burns, annual forb production has decreased and seeded and annual grasses and shrubs shared dominance. The effectiveness of broadcast seeding varied with each burn, aspect, and elevational class. Successful seedings generally can occur on all aspects and elevations if precipitation is normal or above normal the growing season following seeding. If precipitation is below normal, moderate seeding success may be achieved on high-elevation north- and west-facing sites (high-elevation east sites were not found) and low-elevation north-and east-facing sites. Seedling establishment and survival can never be assured because factors such as postseeding precipitation cannot be controlled.

KEYWORDS: broadcast seeding, pinyon-juniper, wildfire, vegetation establishment trends, vegetation survival trends, Nevada, California

Seeding following wildfire is often desirable to control erosion and rapidly restore or increase preburn levels of vegetation. Seeding methods that produce the best results include mechanical seedbed preparation and drilling (Vallentine 1971). Broadcast seedings are often cited as having low potential for success because of depredation of seeds by rodents, birds, and ants, inadequate moisture at the soil surface, and competition from aggressive annual plants (Nelson and others 1970; Campbell and Swain 1973; Goebel and Berry 1976). However, wildfire in pinyon-juniper woodlands in the Great Basin frequently occurs on steep, rocky terrain where only broadcast seeding is practical. This study examined trends in seeded species survival following broadcast seedings on seven burned sites in pinyon-juniper woodlands in Nevada and California. In addition, vegetational patterns on a 1-year-old burn were compared to those on older burns to determine the importance and longevity of initial establishment trends.

METHODS AND ANALYSIS

In 1981 and 1982, eight areas that were broadcast seeded after wildfire were located in pinyon-juniper woodlands in Nevada and California (table 1). On each burn the entire area or a representative part of the burn was surveyed to determine the plant communities present. Sites with major vegetational differences either in species composition or total biomass as well as sites that were similar vegetationally but varied markedly in elevation, aspect, or slope were sampled. Study sites were limited to areas with a minimum of 40 trees per acre (100 trees per hectare). At each site all species were recorded and canopy cover estimated according to the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg 1974). Elevation, slope, and aspect were measured. Only data from sites with slopes greater than 10 percent were used in the analysis.

Qualitative analyses were used to confirm apparent trends. Simple percentages indicated that portion of the total number of sites at north, south, east, and west aspect and high (≧7,000 ft [≧2 120 m]) and low (<7,000 ft [<2 120 m]) elevational classes with a specific range of cover of each vegetational class. Comparisons were made among these groupings and conclusions drawn.

---

[1] Range scientist, located at the Intermountain Station's research work unit maintained in cooperation with the Renewable Resources Center, University of Nevada, Reno, Nev.

Table 1.—*Descriptions of eight pinyon-juniper burn areas in Nevada and California studied to determine success of broadcast seedings*

Study areas	Date of fire	Location description	Average elevation	Average annual precipitation[1]	Percent of normal precipitation in the calendar year following wildfire
			Feet *(m)*	*Inches* *(cm)*	
Big Creek (Nevada)	8/64	T17N R43S Sec 10,15,16	7,290 (2 220)	11.9 (30)	162
Gabbs (Nevada)	8/64	T12N R37E Sec 29	7,010 (2 140)	11.9 (30)	162
Wichmans (Nevada)	7/65	T8N R27E Sec 19,20,30	6,740 (2 055)	9.4 (24)	59
Rock Creek (Calif.)	7/73	T8N R23E Sec 27	6,200 (1,890)	9.4 (24)	85
Pine Nuts (Nevada)	8/73	T11N R22E Sec 19,30 T11N R23E Sec 24,25,36	6,765 (2 060)	12.9 (33)	66
Mt. Wilson (Nevada)	7/74	T4N R68E Sec 1-3,10-15, 21-28	7,160 (2 180)	13.1 (33)	97
China Garden (Calif.)	7/74	T7N R23E Sec 5 T8N R23E Sec 28,29,32,33	6,270 (1 910)	9.4 (24)	110
Slater Mine (Nevada)	8/81	T12N R22E Sec 4-8	6,600 (2 010)	12.9 (33)	[2]145

[1] Based on data from the closest weather station with approximately the same elevation.
[2] Based on data from January 1982 to October 1982.

RESULTS AND DISCUSSION

Establishment Patterns

The Slater Mine Burn was broadcast seeded only 5 months before sampling, and vegetation was still changing rapidly. Intermediate wheatgrass (*Agropyron intermedium* var. *intermedium*) was the dominant seeded species emerging on the Slater Mine Burn. Occurrence appeared to be directly proportional to the degree of establishment of other perennial species and indirectly proportional to the degree of establishment of annual vegetation (table 2). Intermediate wheatgrass was found at low levels of cover (<5 percent) on 100, 79, and 55 percent of the north-, west-, and south-facing sites, respectively (no east-facing slopes were found on the burn). Annual forbs dominated the vegetational response on all aspects of the burn. Cover on the south, and to a lesser extent west, aspects was substantially higher than on the north aspect. Annual grasses, primarily cheatgrass (*Bromus tectorum*), occurred on almost all south- and west-facing sites with cover on the south aspects greater than on west aspects. Only 15 percent of the north-facing sites had annual grass cover. In contrast, perennial species generally had higher occurrence and cover on the north aspect. Shrubs were present on 85 percent of the north-facing sites compared to 45 and

Table 2.—*Vegetational response following wildfire on the Slater Mine Burn indicated by percentage of sites with canopy cover of < 5 percent, 5 to 24 percent, and ≥ 25 percent*

Vegetation	Aspect	Number of sites	Percentage of canopy cover		
			< 5	5-24	≥ 25
Seeded grass	North	13	100	0	0
	South	11	55	0	0
	West	19	79	0	0
Native perennial grass	North	13	84	0	0
	South	11	100	0	0
	West	19	85	0	0
Annual grass	North	13	15	0	0
	South	11	54	18	18
	West	19	79	5	5
Shrubs	North	13	62	15	8
	South	11	45	0	0
	West	19	32	5	0
Annual forbs	North	13	16	54	30
	South	11	0	9	91
	West	19	0	42	58
Perennial forbs	North	13	54	38	8
	South	11	73	18	0
	West	19	63	37	0

37 percent of the south- and west-facing sites, respectively. Perennial forbs were present on most sites but have larger cover values on north aspects than on south or west. Native perennial grasses, however, were more prevalent on south slopes, but cover was low on all aspects.

Conditions on north slopes appear to favor the establishment of seeded grasses and other perennial species. North slopes generally have better moisture relations, less variation in temperature, and generally less harsh conditions than south and west slopes. Conditions limiting annual species occurrence may range from reduction in annual seed reserves in the soil as a result of long-term competitive advantage by perennial species in preburn stands to the occurrence of winter-acquired dormancy in many winter annuals (Baskin and Baskin 1981), which may be prolonged by the cooler temperatures and longer snow cover on north slopes. Site factors also appear to determine the early establishment patterns on south and west aspects. On these sites large daily temperature and moisture differentials, especially in spring and early summer, can easily damage susceptible seedlings. Annual species appear to survive these fluctuations better than most perennial species (Evans and Young 1982; Young and Evans 1982).

A number of vegetational patterns were apparent on the Slater Mine Burn. The longevity of these patterns and their effect on long-term survival of seeded species on this burn is not known. The following examination of vegetational patterns on seven older burns may provide some insight into the importance and longevity of early establishment patterns.

Survival Patterns

The other seven burns sampled varied in age from 5 to 18 years (table 1). Each burned area was vegetationally unique. Mt. Wilson at one end of the spectrum was almost totally dominated by seeded perennial grasses; Pine Nuts on the other end had predominantly annual vegetation (table 3). A high percentage (78 to 100 percent) of sampled sites from each burn had some degree of seeded grass cover. The variation in the percentage of burned sites with seeded grass cover of ≥25 percent ranged from 16 percent on Rock Creek to 100 percent on Mt. Wilson. The three burns with the least cover of seeded grasses (Rock Creek, Pine Nuts, and Wichmans) had the highest percentage of sites with shrub, annual vegetation, and native perennial grass cover of ≥25 percent, respectively. Following the seven wildfires, only these three areas had precipitation less than normal in the calendar year after burning (table 1). Wichmans and Rock Creek areas were seeded in August, contrary to recommended seeding in late fall or early spring (Vallentine 1971). Portions of the Pine Nuts Burn have been continuously grazed by livestock and wild horses since seeding, which may have further discouraged establishment of seeded grasses. Decreased precipitation, and to a lesser extent inappropriate seeding season and grazing pressure, appear to have been crucial in limiting seeding success on these sites. Each individual burn will not be discussed in detail. Data from Wichmans, Rock Creek, and Pine Nuts areas will be combined and compared with data from Big Creek, Gabbs, Mt. Wilson, and China Gardens (table 4). Trends will be discussed with sampled sites being combined into groups based on aspect and elevation.

Cover of seeded grasses was substantially greater on those sites with normal or above normal precipitation the calendar year following wildfire (Big Creek, Gabbs, Mt. Wilson, China Gardens) than on those sites with below normal precipitation during the same period (Wichmans, Rock Creek, China Gardens) (table 4). Cover of seeded grass on those sites with adequate precipitation was generally high over all elevations and aspects. Competition from shrubs may be a factor in reducing seeded grass cover on north slopes and high-elevation east slopes. On burned areas with less than normal precipitation following wildfire, annual vegetation or shrubs appear to have either actively limited seeded grass establishment or filled the void when seeded grass failed to establish because of environmental limitations. Those sites with comparatively low seeded grass cover have both high annual grass and high annual forb cover. Those sites with comparatively high seeded grass cover have substantial amounts of annual grass and shrubs, but cover of annual forbs never exceeds 25 percent. The only exceptions are the high-elevation west slopes, which have relatively high cover of all vegetation classes. Sites with the greatest potential for adequate soil moisture have the highest cover of seeded grass.

Table 3.—*Percentage of sites in seven burned areas with ≥ 25 percent canopy cover by six vegetational classes*

Study area	Number of sites	Seeded grass	Native perennial grass	Annual grass	Shrubs	Annual forbs	Perennial forbs
Big Creek	14	86	0	0	50	0	0
Gabbs	18	44	0	17	6	0	0
Wichmans	9	33	33	22	34	0	0
Rock Creek	19	16	5	26	58	0	0
Pine Nuts	73	27	1	78	22	18	5
Mt. Wilson	26	100	0	4	23	0	4
China Gardens	52	81	0	35	25	0	0

Table 4.—*Percentage of sampled sites from seven burns grouped according to aspect, elevation, and amount of precipitation the calendar year following wildfire with canopy cover ≥25 percent for four vegetational classes*

	Burned areas with below normal precipitation the calendar year following wildfire (Wichmans, Rock Creek, Pine Nuts					Burned areas with normal to above normal precipitation the calendar year following wildfire (Gabbs, China Gardens, Mt. Wilson, Big Creek)				
Aspect	Number of sites	Seeded grass	Annual grass	Shrubs	Annual forbs	Number of sites	Seeded grass	Annual grass	Shrubs	Annual forbs
					All Elevations Combined					
North	50	34	38	50	0	47	66	23	32	0
South	11	0	81	0	45	12	100	17	17	0
East	6	33	83	17	0	25	80	12	24	0
West	34	24	94	12	23	27	89	30	15	0
Total	101	27	64	30	13	111	78	22	28	0
					Elevation ≥7,000 Ft (2 130 m)					
North	7	29	29	86	0	13	54	0	38	0
South	4	0	100	0	50	12	100	17	17	0
East	–	–	–	–	–	14	71	7	29	0
West	8	62	88	38	25	12	91	17	17	0
Total	19	37	68	47	21	51	78	10	25	0
					Elevation <7,000 Ft (2 130 m)					
North	43	35	40	44	0	34	71	32	29	0
South	7	0	71	0	43	–	–	–	–	–
East	6	33	83	17	0	11	91	18	18	0
West	26	12	96	4	23	15	87	40	13	0
Total	82	24	63	26	11	60	77	32	23	0

Environmental factors and competition work in concert to produce a variety of plant distributions which may or may not reflect the original establishment patterns. Annual forbs, so prevalent on the Slater Mine Burn, are found in substantial quantities only on burned sites with below-normal precipitation following wildfire and only on south and west slopes. Competition on all except the driest sites limits annual forb production. Annual species in general tend to be more prevalent on south and west slopes and shrubs on north slopes, similar to the patterns found on Slater Mine. The effects of aspect on the relative distribution patterns of annual vegetation and shrubs remain constant after establishment, regardless of postburning precipitation pattern or elevation. However, the precipitation levels following burning and elevation influence the relative quantities of these vegetation classes, principally by favoring the competitive ability of one class over another.

Distribution of seeded grasses over various aspects and elevations follows no distinctive pattern on the seven older burns. The high incidence of establishment on north slopes, as seen on Slater Mine, is not reflected in the cover values on older burns, probably because of shrub competition. Sites with high shrub cover and sites considered "dry" have reduced seeding success. High postburning precipitation appears to be the dominant environmental factor promoting seeded grass survival, ameliorating any adverse effects elevation or aspect may have. As a result, broadcast seeding success can never be assured because postseeding precipitation cannot be controlled.

PUBLICATIONS CITED

Baskin, J. M.; Baskin, C. C. Ecology of germination and flowering in the weedy winter annual grass *Bromus japonicus*. J. Range Manage. 34: 369-372; 1981.

Campbell, M. H.; Swain, F. G. Factors causing losses during the establishment of surface-sown pastures. J. Range Manage. 26: 355-359; 1973.

Evans, R. A.; Young, J. A. Russian thistle and barbwire Russian thistle seed and seedbed ecology. Agric. Res. Results-W-25. Oakland, CA: U.S. Department of Agriculture, Agricultural Research Service; 1982. 39 p.

Goebel, C. J.; Berry, G. Selectivity of range grass seeds by local birds. J. Range Manage. 29: 393-397; 1976.

Mueller-Dombois, Dieter; Ellenberg, Heinz. Aims and methods of vegetation ecology. New York: John Wiley & Sons; 1974. 547 p.

Nelson, J. R.; Wilson, A. M.; Goebel, C. J. Factors influencing broadcast seeding in bunchgrass range. J. Range Manage. 23: 163-170; 1970.

Vallentine, J. F. Range development and improvements. Provo, UT: Brigham Young University Press; 1971. 516 p.

Young, J. A.; Evans, R. A. Temperature profiles for germination of cool season range grasses. Agric. Res. Results-W-27. Oakland, CA: U.S. Department of Agriculture, Agriculture Research Service; 1982. 92 p.

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-335

November 1983

Constructon Cost and Erosion Control Effectiveness of Filter Windrows on Fill Slopes

**Michael J. Cook
John G. King[1]**

ABSTRACT

Sediment barriers of slash were designed and constructed on the fill slopes of newly constructed roads. These barriers called filter windrows were located in the vicinity of stream crossings in an attempt to prevent eroded fill material from entering the stream. The contractor was able to construct windrows at a rate of 170 ft/h (52 m/h), using a track-mounted Caterpillar 235 hydraulic pull shovel (a large backhoe). The cost of this fill slope treatment was $59 per 100 feet (30 m) of windrowed slope. A conservative estimate of the sediment trapping efficiency of the windrows is 75 to 85 percent, based on measurements of fill slope erosion on windrowed versus non windrowed slopes. The results indicate that the construction of filter windrows on fill slopes is a relatively inexpensive and a very effective treatment for preventing eroded material from entering adjacent streams. Filter windrows can be constructed simultaneously with road construction, providing immediate protection of the water resources.

KEYWORDS: road erosion, sedimentation, erosion control

Surface erosion from roads, especially fill slopes, is greatest during the first year following construction. Megahan's (1972) 6-year study of sediment production from a logging road in the Idaho Batholith revealed that 83.8 percent of the total surface erosion occurred during the first year following construction, with an additional 9.4 percent occurring during the second year. Another study of fill slope erosion in the Horse Creek drainage of north-central Idaho (USDA 1981) reported that 56 percent of the erosion over a 2-year period occurred in the first 2.5 months after construction. Subsequent reduction of the surface erosion rate is due to vegetation establishment and armouring of the slopes.

Slope stabilization measures are often delayed until the autumn following the construction season. Thus, the newly exposed slopes are subject to erosion during convective summer storms. Treatments of seed, fertilizer, and mulch are not completely effective until after seed germination and growth the following spring. Other techniques that incorporate the use of netting or mats are expensive.

The objective of this study was to demonstrate a sediment control technique that utilizes natural materials, provides immediate protection to live streams, requires no additional disturbance width, is esthetically acceptable, and is inexpensive. The technique is to construct sediment barriers, called filter windrows, on the fill slopes adjacent to streams. In this study, filter windrows were constructed with logging slash, long known as a deterrent to sediment movement and readily available from the right-of-way clearing operation. Fill slope erosion was monitored on windrowed and nonwindrowed slopes to quantify the technique's effectiveness.

SITE DESCRIPTION

This project was undertaken in the Horse Creek Administrative-Research Study Area, located in the Nezperce National Forest approximately 35 miles (56 km) east of Grangeville, Idaho (fig. 1). Elevations in the 7,700-acre (3 116-ha) watershed range from 4,110 feet (1 253 m) to 6,025 feet (1 836 m). Grand fir (*Abies grandis*) is the major tree species. Other species include Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), Englemann spruce (*Picea englemannii*), subalpine fir (*Abies lasiocarpa*), and Pacific yew (*Taxus brevifolia*).

---

[1] Michael J. Cook is a forest engineer with the Nezperce National Forest, Grangeville, Idaho; John G. King is a hydrologist located at Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

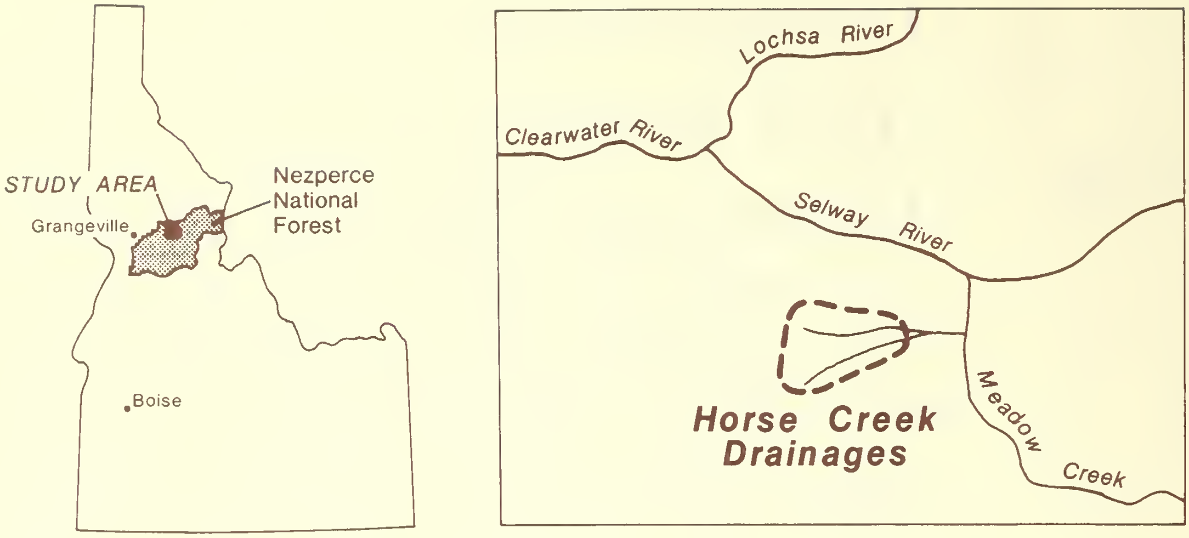


Figure 1.—Location of the Horse Creek Administrative-Research Area.

The area's climate is influenced by modified maritime air masses from the Pacific Ocean. Average annual precipitation is 48 inches (122 cm), 60 to 70 percent of which occurs as snow. The wettest month is January and the driest month is July. Summer convective storms occur from late June through mid-September. The maximum monthly average temperature of 59° F (15° C) occurs in August and the minimum of 17° F (-8° C) occurs in January. Winter temperatures are generally moderate and winter melt is common.

Four major soil types occur in the study area. In order of the percentage of the area they occupy, they are: loessial silt loams, 10 to 30 inches thick (25 to 76 cm); loams to sandy loams, 12 to 30 inches thick (30 to 76 cm); loessial silt loams, 2 to 4 feet thick (61 to 122 cm), overlaying hard mica schist and quartzitic gneisses; and loessial silt loams, 6 to 18 inches thick (15 to 46 cm), overlaying micaecous loams (USDA 1976). The road was constructed on an SM type (silty sand), often grading to a GM type (silty gravels) or a GW type (gravel-sand mixture) at a depth of about 2 feet (60 cm), based on the Unified Soil Classification System (Wotring 1981).

The climate and topography are typical of much of northern Idaho, eastern Washington, and western Montana. Steep slopes and erodible soils present a challenge to land managers concerned with protecting streams, spawning areas, and the total forest ecosystem.

CONSTRUCTION PHASE

Planning

Field work consisted of staking areas for windrow construction, determining the proximity of suitable slash, and selecting stockpile sites. Generally, the entire length of fill slope that could contribute directly to streams was designated for windrow construction. The average length of windrows on the project was 250 feet (76 m), with a range of 70 to 450 feet (21 to 137 m).

Project specifications and a drawing were prepared for inclusion in the road construction contract (appendix). The type of windrow selected was one that would require no additional clearing, would provide a low profile conforming to the fill slope, and would utilize readily available materials.

Construction

Construction was accomplished in two phases. First, during clearing and pioneering at designated sites, suitable material was stockpiled at the upper edge of the staked clearing limits. This did not require any additional time. Coordination between the contractor and engineer insured that stockpile areas would not interfere with planned work and would be conveniently located for later use. Location of stockpiles, either above or below the clearing limits, can easily be modified to accommodate many different clearing operations and contractor requirements.

Second, windrows were constructed by moving a cull log from the stockpile, placing it in position at the toe of the fill, and anchoring it into place against stumps, rocks, or trees with the pull shovel (fig. 2). Stockpiled slash was then placed on the fill slope above the cull log (fig. 3) (see appendix for dimensions). The windrow was compacted by tamping the slash with the shovel. This produced a relatively dense windrow embedded in the top 6 inches (15 cm) of the fill surface. It is important that the slash be embedded to prevent flow of material through or under the slash.

All work in the second phase was accomplished from the road subgrade as fill construction progressed, using a track-mounted Caterpillar 235 hydraulic pull shovel (a large backhoe) with a 360 degree swing. Equipment was the same as that used during the clearing and stockpiling operation. Manual laborers were not required.

All fill slopes were constructed with a 1½:1 slope. The road travelway was stabilized with an 8-inch (20-cm) lift of gravel. In the fall following construction, the fill slopes were seeded, hydromulched, and fertilized.

Figure 2.—Placement of the cull log at the toe of the fill slope.

Figure 3.—Filter windrow 2 years after construction.

Construction Monitoring

Construction was monitored during the clearing and pioneering operation and during filter windrow construction. A total of 1,190 feet (363 m) of windrows were constructed at five stream crossings. All windrows were constructed without interruption.

The total equipment time for construction of all filter windrows was 7.0 hours. Included in equipment time were the equipment move-in and move-out time, the equipment production time, and the average equipment travel speed. Equipment was walked from other work within the project at an average speed of 5 mi/h (8 km/h). Move-in and move-out times were approximately 0.5 hours each. The pull shovel was able to construct 200 lineal feet (61 m) of windrow per hour once at the site. This production time includes movement of cull logs and slash from stockpiles, placement on the slopes, and compaction. Average distance from stockpile to windrow was 350 feet (107 m) and between windrow locations it was 0.2 mile (0.3 km). No equipment breakdowns were encountered. Times will vary with the equipment used and the site. The production rate for windrow construction on this project, considering travel time to the sites, was 1,190 feet (363 m) in 7.0 hours or 170 ft/h (52 m/h).

WINDROW PERFORMANCE

The effectiveness of the filter windrows in preventing eroded material from leaving the fill slopes was measured in two different ways. The first method involved placement of 4-foot-long (1.22-m) troughs, with a capacity of 1 ft^3 (0.03 m^3), immediately below the windrows to collect eroded material transported through or over the windrows. In the second method, the volumes of all rills and gullies in the fill slopes above the windrows and transport distance below the windrows, if any, were measured.

Collection Troughs

Fifteen troughs were installed along the 1,190 feet (363 m) of windrowed fill slopes in 1978, within 1 week following windrow construction. Five troughs were placed below fills with vertical heights of less than 10 feet (3 m), or class 1 slopes. Ten troughs were placed below fills ranging in height from 10 to 20 feet (3 to 6 m), or class 2 slopes. The material in the troughs was removed and volumetrically measured, with an estimated measurement error of ±5 percent, following all major rain storms, once each late fall, and once each spring from July 1978 through August 1981. The volumes of material in the troughs were averaged for the two height categories of fill slopes and are expressed as ft^3/100 ft of road (m^3/1 000 m).

The total amount of eroded material transported through the windrows during the 3 years after road construction was 0.325 ft^3/100 ft (0.302 m^3/1 000 m) for class 1 slopes and 0.650 ft^3/100 ft (0.603 m^3/1 000 m) for class 2 slopes (fig. 4). Erosion of fill slopes not protected with filter windrows for this same period was 35.85 ft^3/100 ft (33.29 m^3/1 000 m) for class 1 slopes and 64.30 ft^3/100 ft (59.70 m^3/1 000 m) for class 2 slopes (fig. 4). Thus, approximately 99 percent of the eroded fill material was deposited within the windrow. Over a 3-year period the windrows reduced the amount of sediment leaving the fill slopes by 163 ft^3 (4.6 m^3) for class 1 slopes and 465 ft^3 (13.2 m^3) for class 2 slopes.

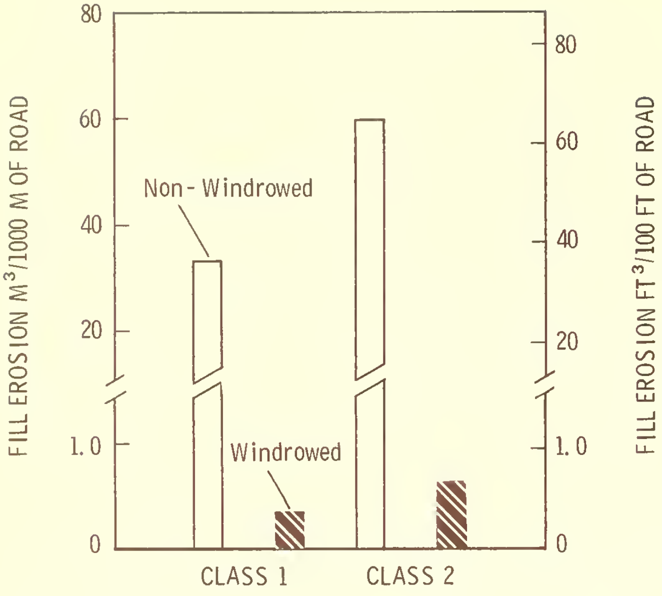


Figure 4.—Fill erosion volumes for windrowed and nonwindrowed slopes by vertical height class during the 3 years following construction.

Gully Surveys

Surveys of the rills and gullies formed in the fill slopes above the filter windrows were made each spring and fall for 3 years following road construction. Measurements of average top width, bottom width, and length of the rills were used to determine volumes, with an estimated measurement error of ±15 percent. In addition, the void volumes of material displaced by slumping above the windrows were measured. If material was transported either through or over the windrow, the downslope travel distance was measured.

The total amount of eroded material transported to all the windrows as rill and gully erosion was 187.0 ft³ (5.3 m³) for the 3-year period. An additional 115.5 ft³ (3.27 m³) of material was displaced by slumping, but the fraction of this slumped material reaching the windrows was not determined.

Figure 5 shows the cumulative rill and gully erosion above the filter windrows. The rate of erosion decreased rapidly with time. After 2 years the slopes were well-vegetated and the majority of the rills and gullies were stabilized. A survey in the summer of 1981 indicated that only 3 of the 36 gullies were still active and that they were beginning to stabilize.

In the 3 years since windrow construction there have been only seven instances when eroded fill slope material was transported past the windrows. Material reached the streams in only three of these instances. Windrow failures were usually associated with slumping, which occurred in late spring when the fill slopes were saturated with snowmelt water. In several cases, the windrows were still partially covered with snow and the slumped material moved over the windrow. In other cases, the subsequent rill erosion in slumped material was transported through the windrows.

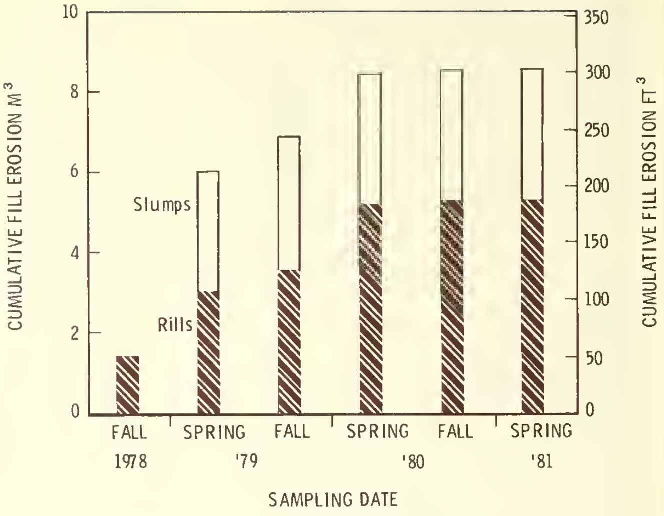


Figure 5.—Cumulative rill and slump erosion of the fills above the filter windrows for the 3 years following construction.

The windrows were effective in reducing downslope transport distance even when they were breached because only a small fraction of the sediment passed through the windrow. Average transport distance below the windrows was 3.8 feet (1.2 m) while average transport distance below unprotected fill slopes was 24.2 feet (7.4 m) if slumping had not occurred and 41.4 feet (12.6 m) below slumped areas of fill.

An accurate determination of the trapping efficiency of the windrows using the rill volume data is not possible because there was no measure of volumes being transported through the windrows. A conservative estimate of trapping efficiency is 75 to 85 percent if the assumption is made that 50 percent of volume was transported through the windrow at each breach.

SUMMARY

The contractor was able to construct 170 feet (52 m) of filter windrow per hour at a cost of $59 per 100 feet (30 m) of windrow. Over the 3 years since construction the windrows have been very effective (75 to 85 percent) in preventing material from leaving fill slopes. The cost of preventing 628 ft³ (17.8 m³) of sediment from leaving the slopes was $700 ($39.33/m³). Total costs will vary with the abundance of suitable materials, travel distances between locations, and care taken in locating and flagging slash stockpiles.

The use of filter windrows on fill slopes at stream crossings is an inexpensive and effective method for minimizing delivery of eroded fill material to streams. With increasing concern over maintaining desirable habitats for trout and anadromous fish, the authors recommend this practice as one means of preventing sediment from entering streams at road crossings. Windrows can be constructed shortly after road pioneering to provide immediate protection to the streams.

Other management considerations relative to the use of filter windrows include fire hazard, the possibility of insect infestation, wildlife movement patterns, and esthetics. As constructed in Horse Creek, big game can easily cross the windrows. If windrows are constructed continuously along the length of the road, perhaps not only for reducing erosion but also for disposing of part of the slash produced during clearing, then these other considerations become more important.

The vertical heights of the windrowed fill slopes ranged from 5 to 20 feet (1.5 to 6.1 m). The effectiveness of windrows on fill slopes with higher erosion rates—for example, on steeper or higher fills, more erosive soils, or sites where revegetation may be slower—may be less than reported for this study.

Eventual decay and weakening of windrows may allow downslope movement of stored sediment in subsequent years if stabilization by revegetation has not occurred. In Horse Creek, virtually all of the fills that were seeded and mulched have excellent vegetative cover. The authors believe that subsequent gradual decay of the slash in the windrows will not cause a significant release of stored sediment for downslope movement. These windrowed slopes will be observed for the next few years to evaluate their long-term performance.

PUBLICATIONS CITED

Megahan, Walter F; Kidd, Walter J. Effect of logging roads on sediment production rates in the Idaho Batholith. Res. Pap. INT-123. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 14 p.

U.S. Department of Agriculture, Forest Service. Interim Report on research: Horse Creek Administrative-Research Project. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 212 p.

U.S. Department of Agriculture. Environmental statement. Kooskia, ID: U.S. Department of Agriculture, Forest Service, Nezperce National Forest. Selway Ranger District; 1976. 47 p. Rep. No. USDA-FS-FES (Adm.) R1-76-5.

U.S Department of Agriculture, Forest Service. Land system inventory: Horse Creek research watershed, Selway Ranger District, Nezperce National Forest. Kooskia, ID: U.S. Department of Agriculture, Forest Service, Nezperce National Forest, Selway Ranger District; 1981. 159 p. Internal report.

APPENDIX
SPECIAL PROJECT SPECIFICATIONS
SECTION 201A - FILTER WINDROW

Description

201A.01 - It is the intent of this specification to provide for the construction of a windrow of logging slash that will act as a sediment trap or filter to reduce erosion effects from newly constructed fill slopes.

Materials

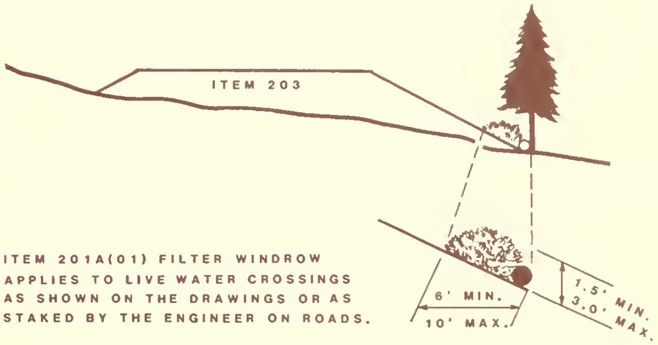
201A.02 - Suitable slash shall be conserved from Item 201(01) Clearing and Grubbing, and stockpiled at approved sites. Slash to be conserved shall consist of tops, limbs, and brush not to exceed 6 inches in diameter, and 12 feet in length. Stumps and root wads shall not be included.

Construction Requirements

201A.03 - Logs of not less than 18-inch diameter shall be placed on the fill slope immediately above and parallel to the toe for the windrow to catch against. Reasonably sound cull logs may be used if available. They shall be firmly anchored against undisturbed stumps, rocks, or trees, or as otherwise directed by the Contracting Officer's Representative (COR).

All material in the windrow shall be placed to form a neat, compact, and uniform pile. Windrows shall be placed so that they do not interfere with the functioning of drainage structures or block stream channels.

Windrows shall be constructed only in locations staked by the COR, on the fill slope immediately above the toe as shown on the drawings.



ITEM 201A(01) FILTER WINDROW APPLIES TO LIVE WATER CROSSINGS AS SHOWN ON THE DRAWINGS OR AS STAKED BY THE ENGINEER ON ROADS.

FILTER WINDROW DIMENSIONS

Methods of Measurement

201A.04 - The amount to be paid for shall be the number of linear feet of windrow, as measured along the toe of the fill, completed and accepted.

Basis of Payment

201A.05 - The accepted quantities of windrow, determined as provided above, will be paid for at the contract unit price, which price and payment will be considered full compensation for the work prescribed in this item. Payment will be made under:

Pay item	Pay unit
201A(01) Filter Windrow..................................	Linear foot

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U.S. GOVERNMENT PRINTING OFFICE: 1983—776-032/1040 REGION NO. 8

nited States
epartment of
griculture

orest Service

**ntermountain
orest and Range
xperiment Station
gden, UT 84401**

esearch Note
NT-336

ovember 1983

Developing Prediction Models for Private Timber Harvest in Montana

**Ervin G. Schuster and
Michael J. Niccolucci[1]**

Developing Prediction Models for Private Timber Harvest in Montana

Ervin G. Schuster and
Michael J. Niccolucci[1]

ABSTRACT

The effects that regional size and various predictive ariables have on predicting nonindustrial private timber arvest in Montana are presented. Multivariable models redicted harvest substantially better than single ariable, price-based models. Multicounty area models vere not consistently better predictors of harvest than he State-level model. Considerable losses in predictive bility relative to area-specific models were found when, or consistency purposes, a common model was used to redict harvest for each area.

KEYWORDS: timber harvest, nonindustrial private owners, modeling, multiple regression

When one thinks of timber harvest on nonindustrial rivate forest land (NIPF), visions of the eastern part of he country come to mind—the Northeast, Midwest, and outh—certainly not the Intermountain West or ontana. These lands are dominated by public forests nd NIPF harvest is of little concern. Right? Well, only artially so. While a decade and a half ago the NIPF ector produced about 2 percent of Montana's timber arvest, it now produces one-fifth of the State's harvest r about 200 million board feet annually (unpublished ata, Northern Region, Forest Service, and Montana ivision of Forestry). Montana's increased NIPF harvest eflects a more general realinement of timber supply ources in the Intermountain region—emphasize private, eemphasize public.

With the increasingly important role played by the IPF base has come increasing interest in better nderstanding and predicting timber harvests from these ands. Concerns historically shown by State forestry rganizations are now being expressed by the Forest ervice, U.S. Department of Agriculture, where the need or forest- and regional-level planning compels more exlicit attention to NIPF timber production.

Unlike the long history of NIPF-oriented investigaions found elsewhere, the Intermountain West and Monana have few or no such traditions. Recently available imber harvest and supply analyses pertaining to these reas are not well-suited to needed evaluations (see USDA Forest Service 1982 and Adams and Haynes 1980). Because these analyses have been directed toward a national timber assessment with eight major regions, relationships for smaller geographical areas were not developed. Additionally, the supply data for the Rocky Mountain region applied to the total private sector, not distinguishing forest industry from NIPF.

The research reported here was conducted in response to a continuing need to predict timber harvest for all producing sectors of the State and sub-State levels. The research hypothesis asserted that substantial improvements could be made by estimating NIPF timber harvest separately from forest industry, by adopting smaller geographical regions, and by expanding the range of predictor variables available. While appearing similar to models of economic supply, models developed were formulated differently to predict timber harvest only.

METHODS

Montana was chosen for study because of its importance in Intermountain States timber production and readily available data. Figure 1 shows the boundaries of the four geographical regions used in this study. Based on available timber production and marketing characteristics, two small multicounty areas were identified—northwestern and southwestern Montana. Either contains a land base greater than Maryland or Vermont. These two areas also were aggregated into a western Montana region, with a land area about the size of West Virginia. The final region consisted of the total State, the fourth largest in the Nation.

Selection of the potential independent variables such as price was based on economic theory, while others such as ownership size were based on previous NIPF studies that identified factors affecting landowner timber harvest behavior. Five broad categories were identified: (a) characteristics of the NIPF land base, (b) economic conditions prevailing in the area, (c) price received for the stumpage, (d) timber harvest behavior of other stumpage producers, and (e) a miscellaneous category.

While theory and previous studies suggested these categories, neither adequately specified the actual variables to be used. Consequently, we selected several candidate variables for each category that had the potential of being useful in prediction. Further, we had a choice of expressing many of these candidate variables in several ways; for instance, dollar-measured candidate variables could be expressed in nominal or constant

---

[1] Research forester and economics assistant, respectively, at the ntermountain Station's Forestry Sciences Laboratory, Missoula, Mont.

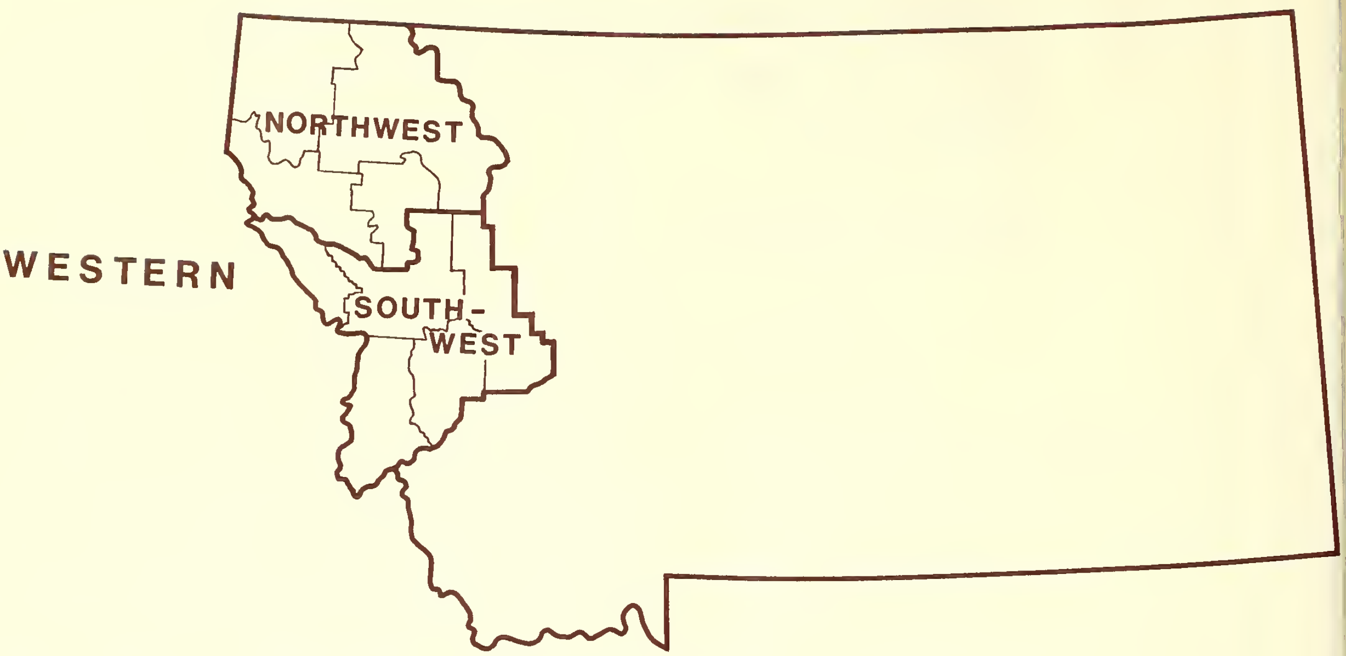


Figure 1.—Montana and three multicounty regions used to assess prediction models in this study.

(real) dollars and most variables could be expressed in current year or previous year (lagged 1 year) levels. Constant dollar conversions used the Gross National Product Implicit Price Deflator, 1972 base. We ultimately treated variables in one of three ways:

Type	Treatments
I	Nominal dollars; current year
II	Nominal and real dollars; current and previous years
III	Nominal dollars; current and previous years

Table 1 summarizes the categories of variables, types of candidate variables, and a treatment code (I, II, or III) for each. In fact, we used even more candidate variables than are indicated. For example, the per capita income variable shown was really represented by three variant forms: per capita personal income, per capita disposable personal income, and per capita nonfarm income, each treated in a Type II manner. In total, we quantified several dozen analysis variables, combinations of candidate variables, variant forms, and methods of treatment.

Data series were developed for the dependent variable, NIPF timber harvest (MMBF, Scribner), and for each of the potential independent variables, for each designated region, for the 16-year period 1965 through 1980. County-level or quasicounty-level data were generally obtained and aggregated into study regions. Savings rates, interest rates, and two price indexes are national in scope. A wide variety of data sources were used.

Data were fit to multiple linear regression models using ordinary least squares and the BMDP stepwise regression computer procedure (Dixon 1981). In linear regression, available data are used to estimate coefficients for the model's independent variables so as to account for as much variability in the dependent variable as possible. Region-specific data for all available years were used to estimate each model. Development of the "best" model proceeded until either no new variables were statistically significant ($\alpha = 0.1$) or when the three most significant variables had been identified (see Draper and Smith 1981).

For the models reported in this paper, the unrestricted, automatic stepping process of the computer

Table 1.—Categories of independent variables, candidate variables, and treatment code (I, II, or III) used to predict NIPF timber harvest

NIPF characteristics	Economic conditions	Price received	Other harvests	Miscellaneous
Acres per owner, I	Per capita income, II	$/MBF, II	National Forest, III	Lumber output, III
Volume per acre, I	Interest rate, national, III		Forest industry, III	Residual, III
Growth per acre, I	Savings rate, national, III		Uncut volume under contract, III	
Timber size, I	Unemployment rate, III			

procedure was frequently interrupted to preclude selection of "redundant" variables. Many candidate variables were handled with variant forms and methods of treatment because of uncertainty as to which form or treatment would prove most useful statistically. When one of these variables was selected by the computer program for inclusion into a model, the related variables were then irrelevant, superfluous to the analysis, and excluded from subsequent consideration. For example, if the per capita personal income variable (real dollars, current year) was selected for inclusion in a model, not only were all other methods of treatment for that variable (for example, nominal dollars, previous year) excluded from future consideration, but the alternative variant forms (such as, per capita disposable personal income and per capita nonfarm income) were excluded as well. Once the "best" models were identified, a series of "all possible combinations" of variables regression runs was made to determine if a preferable model existed but was missed by the stepwise procedure.

All "best" models were tested for statistical significance and consistency with underlying assumptions. Statistical significance of regression coefficients was determined with a two-tailed test. That procedure, which ignores the sign of the coefficient, was judged appropriate for prediction-motivated modeling. Subsequent tests for multicolinearity, heteroscedasticity, and autocorrelation either revealed no problem, or problems were resolved; one autocorrelation test was inconclusive (see Koutsoyiannis 1977). Results presented use the unadjusted coefficient of multiple determination (R^2) rather than the adjusted coefficient because of its understandability while faithfully reflecting the adjusted coefficient in these analyses.

RESULTS

Predictive equations resulting from our modeling efforts seemed quite satisfactory, accounting for three-fourths to almost 90 percent of the variation in NIPF timber harvest. Equations for these, "best" models are shown below for Montana (MT), western Montana (WM), southwestern Montana (SW), and northwestern Montana (NW) regions together with t-statistics, level of significance ($\alpha = 0.01, 0.05$, or 0.10), and the percentage of variation in harvest explained by the model, the R^2.

$$H_t^{MT} = 258.89 + \underset{(6.72,\ .01)}{4.75(P)_t} - \underset{(-2.95,\ .05)}{0.16(Lmbr)_{t-1}} \qquad \ldots R^2 = 80.7$$

$$H_t^{WM} = -27.99 + \underset{(8.15,\ .01)}{2.70(P)_t} + \underset{(-2.60,\ .05)}{8.47(S)_{t-1}} \qquad \ldots R^2 = 83.7$$

$$H_t^{SW} = 95.71 + \underset{(5.22,\ .01)}{0.76(P)_t} - \underset{(-5.29,\ .01)}{1.27(Res)_t} + \underset{(1.86,\ .10)}{2.4(Unemp)_t} \ldots R^2 = 89.3$$

$$H_t^{NW} = -8.37 + \underset{(5.59,\ .01)}{1.30(P)_t} + \underset{(4.48,\ .01)}{0.80(S)_{t-1}^2} \qquad \ldots R^2 = 76.5$$

where:

H = NIPF timber harvest; region (MMBF, Scribner).
P = National Forest stumpage price, cut; region; \$/MBF (1972 \$).
Lmbr = lumber output; region (MMBF).
S = savings rate; nation (percent = savings as percent of personal disposable income).
Res = residual; region (percent = National Forest harvest + industry harvest as percent of lumber output).
Unemp = unemployment rate; region (percent = unemployed workers as percent of labor force).
t = year.

Given the large number of candidate independent variables, the recurrence of certain variables in the "best" models is comforting, if not somewhat surprising. The real price received for National Forest stumpage cut was clearly the single best predictor variable in all four models. We do not contend that National Forest stumpage prices cause NIPF owners to cut timber; clearly they do not. Rather, because no data are available on actual prices paid to NIPF owners, any available price data can only represent an index or proxy for the actual stumpage price received by the landowners. National Forest stumpage cut prices and NIPF stumpage prices probably move together.

In addition to price, the national savings rate (S) was an important predictor variable in the western and northwestern Montana models. In both cases, the "previous year" form of the savings rate variable was used and the sign of the coefficient was positive. The residual variable (Res) was also an important predictor in southwestern and Montana models. In the "current year" form, it had a negative coefficient. Loosely interpreted, this variable represents (on a percentage basis) the proportion of the region's lumber output accounted for by timber harvested from industry and National Forest lands. The higher the proportion, the lower the NIPF harvest. It portrays NIPF harvest as filling an unmet or residual need for timber. The "previous year" form of the lumber output variable (Lmbr) was significant in the Montana model. Finally, unemployment rate was important in the southwestern Montana model, being positively related to NIPF harvest. The higher the rate of unemployment, the higher the harvest.

All "best" models accounted for a substantial portion of the variation in NIPF timber harvest, as reflected by the relatively large R^2 values. The larger this value, the more variation explained by the model, and the more useful the model is in prediction. Table 2 shows a comparison of the actual NIPF harvest and the harvest predicted by the "best" model, for each region. The "best" models vary in prediction ability. The northwestern, southwestern, and western Montana models had the smallest average, annual percentage difference between observed and predicted, each averaging just under 10 percent over the 16-year period. The Montana model had the largest differences, averaging about 13 percent per year over the period. These larger differences are, no doubt, related to the volatility of eastern Montana harvest.

Derivation of predicted harvest levels can be illustrated by the southwest model for 1980. Given the 1980 level for real price (P = \$20.87/MBF), residual (Res = 77.0 percent), and unemployment (Unemp = 7.5 percent), the level of harvest is predicted as follows:

$$\begin{aligned} H_{1980}^{SW} &= 95.71 + 0.76(20.87) - 1.27(77.0) + 2.4(7.5) \\ &= 31.4 \text{ MMBF} \end{aligned}$$

Table 2.— Comparison of actual NIPF timber harvest and that predicted by "best" models, by region, 1965-80

Year	Northwestern		Southwestern		Western		Montana	
	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
	Million board feet							
1965	43.6	59.0	19.9	18.7	64.3	77.7	112.3	124.4
1966	41.9	36.7	13.3	12.1	63.1	48.8	108.5	105.1
1967	44.7	42.8	18.5	19.1	65.1	61.8	99.8	98.4
1968	61.2	49.3	23.8	21.8	84.1	71.1	121.5	99.9
1969	70.9	63.9	35.9	45.6	117.1	109.5	160.3	151.2
1970	49.4	49.0	43.3	39.3	84.9	88.3	138.9	140.0
1971	61.7	72.5	24.6	27.1	86.5	99.6	140.3	180.1
1972	82.1	92.1	34.3	30.7	122.1	122.8	173.1	134.9
1973	69.6	75.2	56.8	53.6	118.8	128.9	200.6	215.7
1974	86.4	86.7	40.1	46.5	134.9	133.2	184.9	229.7
1975	64.6	53.3	37.8	30.7	95.2	84.0	176.2	148.7
1976	70.5	67.2	47.9	49.5	105.8	116.7	214.7	231.1
1977	61.3	61.3	56.4	64.6	110.1	125.9	222.0	218.2
1978	63.2	65.4	49.9	51.5	114.5	116.9	227.6	222.2
1979	65.9	62.9	57.7	44.9	129.9	112.9	238.3	227.9
1980	42.6	42.0	31.4	31.2	74.6	73.2	157.4	148.6

Estimates for other regions and years are similarly derived. The estimate for the 1981 harvest, a year outside the modeling data base, in the southeastern region is calculated as follows:

$$
\begin{aligned}
H^{SW}_{1981} &= 95.71 + 0.76(21.85) - 1.27(86.1) + 2.4(9.2) \\
&= 25.0 \text{ MMBF}
\end{aligned}
$$

The actual level of the 1981 harvest for that region was 25.1 MMBF. Differences between the predicted and actual harvests for the northwestern and western Montana regions were typical of the 16-year period; that for Montana exceeded the typical difference.

One purpose of our work was to see if improvements in predicting NIPF harvest could be made by expanding the range of independent variables considered. We found that although addition of the second and third variables could markedly improve prediction, choice of the first variable was critical. Table 3 shows a comparison of model explanation capability (R^2) between single variable models using several real price-based variables and the multiple-variable "best" models. As shown, improvements can be made over single, price-based variable models by including more explanatory variables. The largest improvement, a 90 percent increase, was obtained in the two-variable northwestern model, relative to the best price-based model. This point is further emphasized when the multivariable models are compared to a widely used price variable, National Forest stumpage (sold) price.

Substantial prediction improvements can be made by using the "correct" price variable. Inspection of the

Table 3.—Comparison of explanatory ability (R^2) for alternative "real" price-based models relative to "best" multivariable models, by region

Region	Alternative price measures/indexes[1]					"Best" model;[2] variables =		
	WWPA[3]	WPI[4]	Mont[5]	NFS[6]	NFC[7]	1	2	3
Montana	18.5	52.0	57.2	30.7	67.7	67.7	80.7	—
Western	0.3	22.7	49.8	55.2	75.2	75.2	83.7	—
Southwestern	7.0	44.2	49.8	50.3	55.5	55.5	86.2	89.3
Northwestern	2.7	2.5	25.4	16.8	40.2	40.2	76.5	—

[1] Equivalent models using "current" prices were substantially inferior to "real" price models.
[2] Independent variables significant at a = 0.10 level, or better.
[3] Western Wood Products Association, price index, dry Douglas-fir and larch, real.
[4] Wholesale Price Index, lumber and wood products, 1972 base.
[5] Montana Division of Forestry stumpage price, sold, $/MBF, real.
[6] National Forest stumpage price, sold, $/MBF, real.
[7] National Forest stumpage price, cut, $/MBF, real.

predictive power of alternative price measures/indexes shows wide variation. The Western Wood Products Association price index is generally the worst, and the National Forest stumpage (cut) price is always the best. In all cases, real prices were found to be far more useful in prediction than their nominal price counterparts. All this suggests a need for analysts to rather carefully choose type of price variable to use.

Another purpose served in this study was to determine the extent to which improvements in predicting NIPF harvest could be secured by focusing on smaller geographical areas. Frankly, we expected substantial improvements. But this was not the case. Table 3 shows mixed results. A comparison between the "best" one-, two-, or three- variable models associated with increasingly larger regions (NW and SW, to WM, to Montana) shows no consistent pattern. Models for the smaller regions were better or worse than those for large ones, depending on the specific regions being compared and the number of variables in the models. These results are suggestive only, definitive conclusions being possible only from more extensive research involving replications. Nevertheless, we speculate that major improvements in predictability were secured by initially focusing on a single State rather than a large, multi-State region.

Timber harvest for western Montana can be predicted in one of two ways. It can be predicted directly by use of its "best" model as described earlier. It can also be predicted by summing the predicted harvests for the northwestern and southwestern regions. These summations provided a better (or at least equivalent) approximation of the actual harvest in western Montana than did the "best" model for two-thirds of the study years. Since a separate model for eastern Montana was not developed, we could not assess whether the sum of eastern plus western Montana provided a better approximation of the Montana harvest than did the Montana "best" model. We expect, however, that this would be the case.

Finally, we present results of analyses that modeled each area's timber cut by the variables contained in the "best" model for each other area. This was done to determine the extent to which the need (perceived or required) for model consistency between regions entailed a loss of predictive ability, measured by R^2. As planning efforts in forestry expand, there is a tendency to require procedures that ensure uniformity and comparability.

Results shown in table 4 indicate a mixed response again. The R^2 values shown are frequently exaggerated since they correspond to models that may contain statistically insignificant variables. The northwestern, southwestern, and western Montana models all explained an average of 72 percent of the variation in harvest while the Montana model averaged about 10 percent less. However, although the northwestern and western Montana models produced results that varied only by about 22 percent between regions, the Montana model produced results that varied by about 37 percent and the southwestern model by 43 percent. These results suggest that consistency can be achieved only at the expense of predictive power, a substantial loss in some cases. The southwestern, northwestern, and western Montana models all generated an average loss of about 14 percent per (outside) region. The Montana model has the largest loss, averaging about 23 percent per region. Regardless, either the largest or smallest decrease would generally be considered to be an appreciable loss in predictive power.

The consequence of model consistency can be shown by subsequent analysis of the southwestern model when applied to other regions. Three sets of regression models are shown, one for each region using the variables in the southwestern model:

$$H_t^{MT} = 59.6 + \underset{(2.90,\ .05)}{4.0(P)_t} - \underset{(n.s.)}{62.7(Res)_t} + \underset{(n.s.)}{9.4(Unemp)_t} \quad \ldots R^2 = 70.5$$

$$= 99.9 + \underset{(4.64,\ .01)}{4.4(P)_t} - \underset{(n.s.)}{56.3\ (Res)_t} \quad \ldots R^2 = 68.1$$

$$= 51.9 + \underset{(5.42,\ .01)}{4.8(P)_t} \quad \ldots R^2 = 67.8$$

$$H_t^{WM} = 112.1 + \underset{(3.72,\ .01)}{1.9(P)_t} - \underset{(-1.73,\ \cong .10)}{142.4(Res)_t} + \underset{(n.s.)}{5.7(Unemp)_t} \ldots R^2 = 80.2$$

$$= 78.4 + \underset{(5.98,\ .01)}{2.4(P)_t} - \underset{(n.s.)}{59.3(Res)_t} \quad \ldots R^2 = 76.9$$

$$= 33.0 + \underset{(6.52,\ .01)}{2.4(P)_t} \quad \ldots R^2 = 75.2$$

$$H_t^{NW} = 83.0 + \underset{(n.s.)}{0.8(P)_t} - \underset{(n.s.)}{56.8(Res)_t} + \underset{(n.s.)}{0.7(Unemp)_t} \quad \ldots R^2 = 46.6$$

$$= 81.2 + \underset{(2.52,\ .05)}{0.9(P)_t} - \underset{(n.s.)}{51.0(Res)_t} \quad \ldots R^2 = 46.4$$

$$= 32.3 + \underset{(3.07,\ .01)}{1.1(P)_t} \quad \ldots R^2 = 40.2$$

Table 4.—Comparison of explanatory ability (R^2) of "best" model for each region applied to other regions

Region "best" model for	"Best" model applied to				
	Northwestern	Southwestern	Western	Montana	Average
Montana	43.5	62.2	75.3	80.7	65.4
Western	76.3	61.2	83.7	67.9	72.3
Southwestern	46.6	89.3	80.2	70.5	71.7
Northwestern	76.5	61.3	83.5	67.9	72.3

All variables, t-statistics, and significance levels are as given earlier. These analyses rather clearly show that if statistical significance (at $\alpha = 0.10$) of regression coefficients is a requirement in model selection, the three-variable southwestern model is not feasible in any case, other than the southwest. In conjunction with the other variables, the unemployment rate variable is not significant [(n.s.)] in all cases. When the data are fit to the two-variable, (P and Res) model, the residual (Res) variable is again not significant in any of the three regions. Only the price variable (P) is statistically significant in all regions. Stated differently, starting from the three-variable southwestern model, the only model that could be consistently applied to all regions (with the significant coefficient requirement) is the single-variable price model. In fact, that model is the best, consistent, single-variable model in light of all possible variables.

DISCUSSION

Three general conclusions derive from this study. First, highly satisfactory models can be developed to predict NIPF timber harvest, if the appropriate variables have been quantified. In particular, results would have been much less satisfactory without use of the "cut" version of National Forest stumpage price, expressed in real dollars. Without the detailed county-level records on NIPF timber harvest, our analysis of Montana regions simply could not have taken place. This type of record is not consistently available in all States. Second, the ability to develop better predictive models for small areas compared to larger areas was not uniform. Sometimes it worked; sometimes it did not. This suggests that the assumed advantage of regional forecasting, reducing variability, does not always occur. Third, use of the same model to predict timber harvest for different regions has both advantages and disadvantages. The clear advantages are consistency and the attendant ease in understanding the model and interpreting results. But these advantages can only be secured by a loss of predictive ability. Results presented indicate that the loss can be substantial or nearly inconsequental.

Throughout this report, the coefficient of multiple determination (R^2) has been used as the basis for comparisons and for judging model superiority. While a convenient measure, R^2 alone is probably an inadequate basis for such judgments. Other measures such as adjusted R^2, standard errors, and ease of quantifying independent variables should also be considered. Moreover, although some of the R^2 values presented were substantially different from others, some were quite close. An R^2 of 80.2 may be statistically different from 83.7, but the difference could be judged trivially small in a practical application. The ultimate determination that one model is "close enough" to another is a judgment that must be based on the needs and priorities of the user.

REFERENCES

Adams, Darius M.; Haynes, Richard W. The 1980 timber assessment market model: stumpage projections and policy simulations. For. Sci. Monogr. 22; 1980. 64 p.

Dixon, W. J., ed. BMDP statistical software. Berkeley, CA: University of California Press; 1981. 725 p.

Draper, N. R.; Smith, H. Applied regression analysis. 2d ed. New York: John Wiley and Sons; 1981. 709 p.

Koutsoyiannis, A. Theory of econometrics. 2d ed. New York: MacMillan; 1977. 681 p.

U.S. Department of Agriculture, Forest Service. An analysis of the timber situation in the United States 1952-2030. Res. Rep. 23. Washington, DC: U.S. Department of Agriculture, Forest Service; 1982. 499 p.

U.S. GOVERNMENT PRINTING OFFICE: 1983—776-032/1046 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-337

November 1983

Seed Transfer Guidelines for Douglas-fir in Central Idaho

G. E. Rehfeldt[1]

ABSTRACT

Seed transfer guidelines are presented for Douglas-fir in central Idaho. While geographically lateral transfers may be relatively broad, elevational transfers should be limited to ±330 feet from the elevation of the seed source.

KEYWORDS: seed transfer, seed zones, adaptive variation

By limiting the distance that seeds are moved from their origin, seed transfer guidelines provide assurance that planted trees are adapted to the environment in which they are planted. To assure adaptation, however, guidelines must be based on genetic differences among populations that reflect adaptations to natural environments. This note presents seed transfer guidelines for Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) in central Idaho. The guidelines are developed from patterns of adaptive variation presented previously (Rehfeldt 1983). Limits to seed transfer are defined as the minimum geographic or elevational interval across which differentiation is detected with a probability of about 80 percent (Rehfeldt 1979).

PATTERNS OF VARIATION

Analyses of eight variables reflecting growth potential and cold hardiness revealed that adaptation of Douglas-fir populations in central Idaho results from a balance between selection for high growth potential by mild environments and selection for cold hardiness by severe environments (Rehfeldt 1983). As a result, genetic differentiation among populations is closely related to the elevation, geographic setting, and climate of the seed origin. These variables, in fact, accounted for as much as 87 percent of the genetic variance among populations.

As elevation increases, the length of the frost-free period generally decreases. Consequently, elevation of the seed source is negatively associated with growth potential but positively associated with cold hardiness. These elevational clines, like those for Douglas-fir in northern Idaho (Rehfeldt 1979) and western Montana (Rehfeldt 1982), are steep. On the average, populations separated by 3,300 feet in central Idaho differ by 48 percent of the mean height of all populations (Rehfeldt 1983). In addition, populations separated by 3,300 feet are expected to differ by about 28 percent in damage from freezing when injury to all populations reaches 50 percent (Rehfeldt 1979).

Geographic patterns of genetic variation that are independent of elevation are also evident in central Idaho (fig. 1). These patterns are closely related to environmental gradients. Ross and Savage (1967) show that frost-free periods are the longest (up to 180 days) in the northwestern portion of the region but abruptly drop to less than 60 days toward the southeast. Patterns of genetic variation, illustrated in figure 1 by contours of relatively equal performance, duplicate the environmental patterns. When elevation is held constant, populations from the northwest express greater growth potential but lesser cold hardiness than populations from the southeast. On the average, populations located at similar elevations in adjacent contour bands (fig. 1) differ by 5 percent in 3-year height and by 3 percent in cold injury.

Seed Transfer

Patterns of genetic variation can be used to limit seed transfer by using the following information: (1) contour intervals (fig. 1) are scaled to a value of one-half the geographic distance at which differentiation could be detected (80 percent level), and (2) differences could be detected (80 percent level) among populations separated by 660 feet elevation. From this information, either discrete seed zones or floating transfer guidelines can be constructed.

Discrete seed zones are separate and distinct parcels of land. Such zones should include two contour bands and 660 feet elevation. Transfers from a single source should be limited to ±330 feet and ±1 contour.

---

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

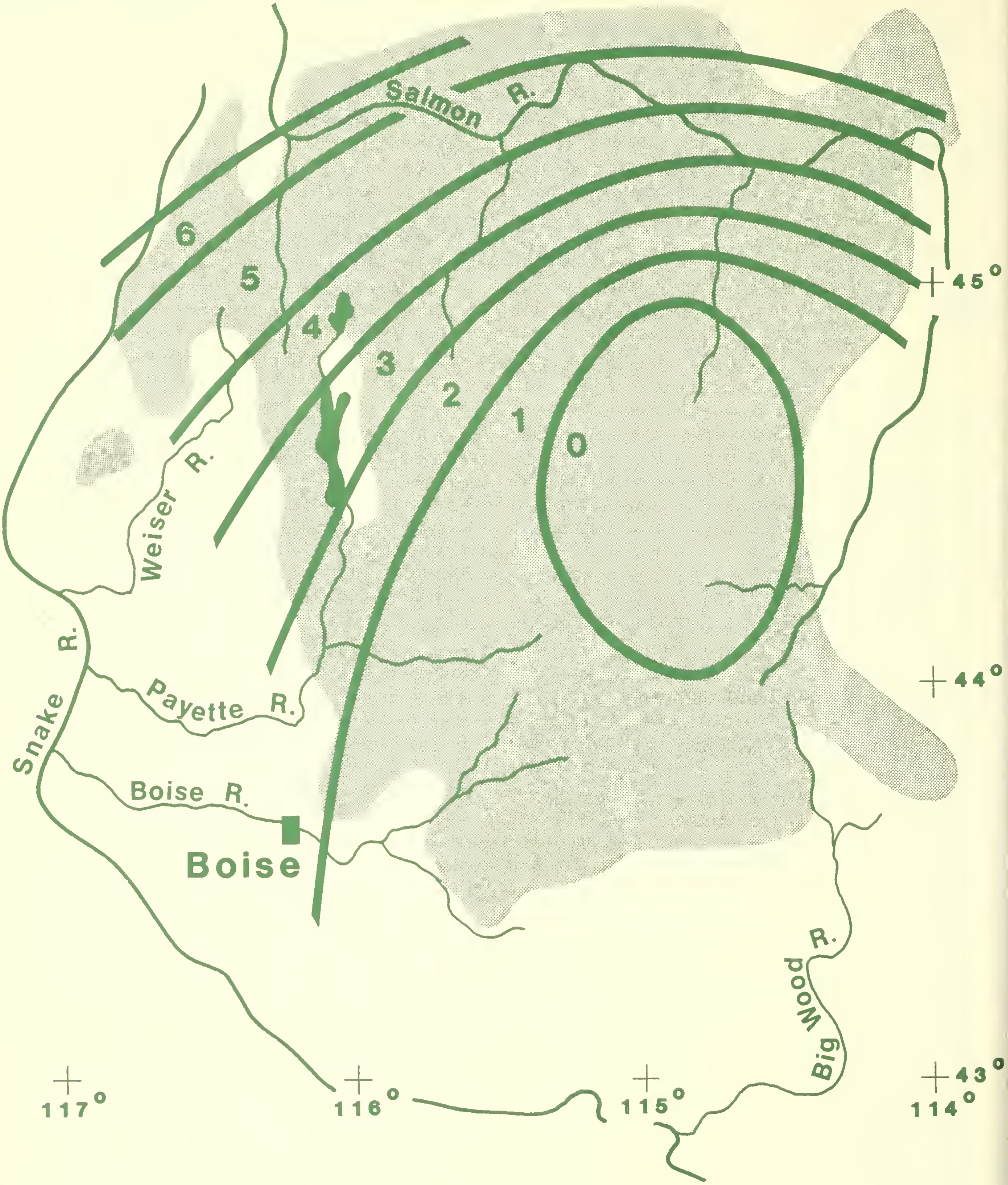


Figure 1. Geographic patterns of genetic variation among populations of Douglas-fir in central Idaho. The zero contour band depicts populations of lowest growth potential but highest cold hardiness.

Floating transfer guidelines are constructed from the relationship between elevational and geographic differentiation. From the genetic viewpoint, seed transfer from a contour band (fig. 1) of high numeric value to a band of ow value is similar to a transfer of 330 feet upward in elevation within a band. Thus, seed can be transferred across contours; but each time a contour is crossed, an adjustment must be made in the elevational interval at which that seed is used. When seed is transferred across bands of decreasing numeric value, the appropriate elevational interval should be lowered by 330 feet for each contour crossed. When seed is transferred across bands of increasing numeric value, the interval should be ncreased by 330 feet. For example, if seed is collected from 4,500 feet in band 3, the seed may be used between 4,170 and 4,830 feet (4,500 ± 330) within that band. In band 2, it may be used between 3,840 and 4,500 feet 4,170 ± 330); in band 4, it may be used between 4,500 and 5,160 feet (4,830 ± 330). Seeds, however, should not be transferred across more than four bands. Regardless, floating transfer guidelines provide administrative flexbility; a single seed production area may serve several geographic bands.

Small geographic and narrow elevational limits to seed transfer may be impractical or uneconomical administratively. But expanding the recommended limits of seed transfer increases the risk of losses in productivity n two ways. First, whenever seed adapted to a severe environment is planted in a mild environment, growth potential, as compared to local populations, is reduced. Second, whenever seed from a mild environment is planted in a severe environment, damage from the cold is increased. Estimated losses average 5 percent in 3-year height and about 3 percent in frost injuries for each contour or for each 330 feet elevation that seed is moved from its origin.

The effects of seed transfer based on juvenile data cannot be transcribed accurately into productive losses of mature forests. Losses in productivity caused by maladaptation, however, accrue throughout the life cycle. Consequently, future information may require alteration of the present guidelines. Regardless, there is little doubt that dramatic consequences can develop from the indiscriminant transfer of Douglas-fir seeds in central Idaho.

REFERENCES

Rehfeldt, G. E. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. I. North Idaho and northeast Washington. Heredity. 43: 383-397; 1979.

Rehfeldt, G. E. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. II. Western Montana. Res. Pap. INT-295. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 8 p.

Rehfeldt, G. E. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. III. Central Idaho. Can. J. For. Res. 13: 626-632. 1983.

Ross, S. H.; Savage, C. N. Idaho earth science. Moscow, ID: Idaho Bureau of Mines; 1967. 271 p.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U.S. GOVERNMENT PRINTING OFFICE: 1983—776-032/1049 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-338

December 1983

Strategy for Reducing Mountain Pine Beetle Infestations with Ponderosa Pine Trap Logs

Gene D. Amman[1]

ABSTRACT

Mountain pine beetles were strongly attracted to ponderosa pine logs in decks. Of 283 logs cut in June and July and placed in decks, 74.9 percent became infested by mountain pine beetles. These observations suggest that ponderosa pine trap logs cut before beetle flight could attract a large proportion of beetles in a stand. The infested logs then could be removed to reduce the beetle population in the area.

KEYWORDS: *Dendroctonus ponderosae*, *Pinus ponderosa*, trap log

INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has been epidemic in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) on the Escalante Ranger District, Dixie National Forest, in southern Utah since about 1977. District personnel have initiated a harvest and thinning program to place ponderosa pine stands under management and thus reduce losses to the beetle.

Aerial observers noted trees killed by mountain pine beetles in the mid-1960's with a large increase in 1978 (Thier and Beveridge 1979). In 1979, 50 trees per acre (123.6/ha) were infested in the most intense part of the infestation located east of Cowpuncher Guard Station in the Pine Creek drainage (Thier and Beveridge 1979). Trees infested by mountain pine beetles ranged between 2 and 47 inches (5.1 and 119.4 cm) in diameter at breast height (d.b.h.), with trees in diameter classes larger than 20 inches (50.8 cm) killed proportionately at a greater rate than trees in smaller diameter classes (unpublished data, Intermountain Forest and Range Experiment Station, Ogden, Utah).

Stand surveys in the Pine Creek drainage in October 1982 revealed very few freshly attacked trees compared to numbers infested in 1981. The low number of infested trees suggested that beetles may have been attracted to felled trees and then removed as the logs were hauled to sawmill sites outside the area.

Mountain pine beetles have been known to infest windthrown ponderosa pine trees and trap logs, particularly logs freshly cut just before and during the flight period (Beal 1939; Blackman 1931; Hopkins 1905; Parker and Stevens 1979; Weaver 1934). Trap logs have been considered a way to attract beetles and remove them from the forest, thus reducing the beetle population.

Although the mountain pine beetle appears to be strongly attracted to felled ponderosa pine, this does not hold for lodgepole pine. Beetles infest the undersides of windthrown lodgepole pine, but do not show a strong attraction to felled trees, including log decks. Only an occasional beetle will infest lodgepole pine logs; most of the population is strongly attracted to standing green trees.

The purpose of this report is to present data on the incidence of mountain pine beetles infesting ponderosa pine logs in decks and a suggested strategy for trap log cutting and removal to reduce beetle populations.

METHODS

All logs cut in the Pine Creek drainage had been hauled to the sawmill by October 1982. Therefore, the opportunity to survey logs for mountain pine beetle infestation was lost. However, logs had not been removed from the adjacent Blue Springs Creek drainage, which was selected for examination of freshly infested standing trees and infested logs. Several hundred trees infested in the Blue Springs Creek drainage in 1981 had potential to produce many beetles.

---

[1] Principal entomologist, Population Dynamics of the Mountain Pine Beetle Research Work Unit, Ogden, Utah.

Two strip surveys were conducted for standing infested trees. The first survey was in October 1982 and was for newly infested trees (1982) only. Four observers walked a strip 8 chains wide by 80 chains long (161 by 1 609 m), resulting in coverage of 64 acres (25.9 ha).

The second survey covered a different part of the drainage and was for all infested trees. Two observers walked a strip 2 chains wide by 140 chains long (40 by 2 816 m), resulting in coverage of 28 acres (11.3 ha). Trees were categorized by year of death: 1982, 1981, 1980, and all trees killed before 1980.

Logs in 10 decks, consisting of trees cleared for road construction into the Blue Springs Creek drainage, were examined for bark beetle infestation (fig. 1). Some bark was removed with an ax from logs where beetles were boring to determine the species of beetle involved. Logs that could not be reached, usually those in the bottom of the deck, were checked for boring frass of bark beetles. Frass of *Dendroctonus* sp. generally is coarser than that of *Ips pini*, the other species of bark beetle found in the decks. In addition, logs in two decks and those lying in the forest, which were cut after road construction was completed, were examined for beetle infestation.

Figure 1.—Ponderosa pine log decks of trees felled in June and July during road construction were subsequently infested by mountain pine beetles.

RESULTS

The 1982 strip surveys revealed a total of 13.3 trees per acre (32.9/ha) killed during the epidemic, but no newly infested trees even though an estimated 2.2 trees per acre (5.4/ha) were infested in 1981 (table 1). Trees infested in 1981 were significantly smaller than those infested in the earlier years of the infestation (12.7 inches versus 10.8 inches [32.3 versus 27.4 cm] d.b.h.), but not significantly smaller than those infested in 1980 (12.0 inches [30.5 cm] d.b.h.).

The 10 log decks contained a total of 283 logs (range 9 to 42 per deck), 8 to 30 inches (20.3 to 76.2 cm) in diameter, and 32 ft (9.72 m) long. Of these, 212, or 74.9 percent, were infested by mountain pine beetles (range 40.9 to 100 percent per deck) (table 2). Two of the decks contained logs infested by *Ips pini* (7.1 and 23.5 percent of the logs, respectively), for a total of seven, or 2.5 percent of the total logs. Logs infested by *Ips* were the smallest, being 8 to 10 inches (20.3 to 25.4 cm) in diameter. Mountain pine beetle and *Ips* brood ranged from egg to third instar larvae.

Table 1.—Numbers and average d.b.h. of ponderosa pine trees killed by mountain pine beetles, Blue Springs Creek drainage, Escalante Ranger District, Dixie National Forest, Utah

Year	Trees killed per acre	Average d.b.h. $\bar{x}$	sd	
	Number	*Inches*		
1979 and earlier	8.0	[1]12.7	2.35	(n = 235)
1980	3.1	12.0	2.12	(n = 87)
1981	2.2	[1]10.8	1.93	(n = 61)
1982	0.0	—	—	—
All years	13.3	12.3	2.26	(n = 383)

[1] Means significantly different at 0.05 level (t-test).

Table 2.—Numbers and percents of decked ponderosa pine logs infested in 1982 by mountain pine beetle and *Ips pini*, Blue Springs Creek drainage, Escalante Ranger District, Dixie National Forest, Utah

Log deck	Logs examined	Logs infested by mountain pine beetles		Logs infested by *Ips pini*	
	No.	*No.*	*Percent*	*No.*	*Percent*
1	27	23	85.2	0	0
2	41	37	90.2	0	0
3	17	11	64.7	4	23.5
4	22	9	40.9	0	0
5	9	9	100.0	0	0
6	35	19	54.3	0	0
7	36	19	52.8	0	0
8	42	38	90.5	0	0
9	12	12	100.0	0	0
10	42	35	83.3	3	7.1
Total	283	212	74.9	7	2.5

Log decks consisting of trees felled during the logging operation following road right-of-way construction did not contain bark beetles. Trees felled during the logging operation, but still lying in the forest, also did not contain beetles.

DISCUSSION

The lack of newly infested trees in the Blue Springs Creek drainage appears to be largely related to mountain pine beetles infesting logs in decks. Trees for the road right-of-way were felled and logs decked during June and early July before mountain pine beetle emergence, but after overwintering *Ips pini* would have emerged and infested trees or slash. Therefore, the logs appear to have provided a strong attraction to mountain pine beetles emerging during the flight period, which occurred from about mid-August to mid-September. Range in beetle stages from egg to third instar suggests a prolonged emergence period for attacking beetles.

Frequent rains and cool temperatures appeared to delay emergence as indicated by beetle cage and trap catches from mid-August to early September (unpublished data, Research Work Unit 2201, Intermountain Forest and Range Experiment Station, Ogden, Utah). Adverse weather during the flight period also could have affected the number of successfully infested trees by prolonging the emergence period (McCambridge 1964).

A prolonged emergence period results in too few beetles emerging at one time to successfully mass attack most standing trees selected for infestation, and results in a high ratio of unsuccessfully to successfully attacked trees. In the adjacent Pine Creek drainage, eight trees were successfully infested and eight were not.

APPLICATION

These data suggest that land managers faced with a large beetle infestation in ponderosa pine could, with proper timing of logging, greatly reduce the beetle population. By felling trees in June and July before beetle flight, downed trees and log decks should attract many beetles, with attack densities comparable to those in standing trees (Blackman 1931; Parker and Stevens 1979). The logs and trees then can be removed from the forest before beetle flight the following year. It is important that infested logs be removed from the forest before beetles complete development and emerge the year following attack.

Logs taken to sawmills should be processed promptly, and infested slabs and cull logs should be burned, debarked, or dried to destroy brood before they mature and emerge. Beetles emerging in urban areas could be expected to infest most species of pine, including exotics (McCambridge 1975; Furniss and Schenk 1969; Smith and others 1981). Without slab and cull treatments at mills in forested areas, emerging beetles may start an outbreak in the vicinity of the sawmill, with the infestation spreading into adjacent stands.

REFERENCES

Beal, J. A. The Black Hills beetle, a serious enemy of Rocky Mountain pines. Farmers Bull. 1824. Washington, DC: U.S. Department of Agriculture; 1939. 21 p.

Blackman, M. W. The Black Hills beetle. Tech. Publ. No. 36. Syracuse NY: Syracuse University, New York State College of Forestry; 1931. 77 p.

Furniss, M. M.; Schenk, J. A. Sustained natural infestation by the mountain pine beetle in seven new *Pinus* and *Picea* hosts. J. Econ.Entomol. 62: 518-519; 1969.

Hopkins, A. D. The Black Hills beetle. Bull. 56. Washington, DC: U.S. Department of Agriculture, Bureau of Entomology; 1905. 24 p.

McCambridge, William F. Emergence period of Black Hills beetles from ponderosa pine in the central Rocky Mountains. Res. Note RM-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1964. 4 p.

McCambridge, William F. Scotch pine and mountain pine beetles. Green Thumb. 32: 87; 1975.

Parker, Douglas L.; Stevens, Robert E. Mountain pine beetle infestation characteristics in ponderosa pine, Kaibab Plateau, Arizona, 1975-1977. Res. Note RM-367. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 4 p.

Smith, Richard H.; Cramer, John P.; Carpender, Edwin J. New record of introduced hosts for mountain pine beetle in California. Res. Note PSW-354. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1981. 3 p.

Thier, R. W.; Beveridge, Ron. Bark beetle infestation for proposed Grimes Creek and Side Hollow timber sales. Biol. Eval. Rep. R-4 80-1. Boise, ID: U.S. Department of Agriculture, Forest Service; 1979. 9 p.

Weaver, Harold. The development and control of pine beetle epidemics. J. For. 32: 100-103; 1934.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of idaho)

Provo, Utah (in cooperlation with Brigham Young University)

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

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—776-032/1051 REGION NO. 8

A 13.79: INT- Research Note number 339
is missing from our collection and
cannot be obtained.

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, Utah 84401**

Research Note
INT-340

April 1984

Early Developmental Differences among Five Lodgepole Pine Provenances Planted on a Subalpine Site in Montana

**Dennis M. Cole
Ward W. McCaughey**

Early Developmental Differences among Five Lodgepole Pine Provenances Planted on a Subalpine Site in Montana

Dennis M. Cole
Ward M. McCaughey[1]

ABSTRACT

Lodgepole pine seedlings from British Columbia, Washington, Idaho, and Utah were planted along with a local provenance on a high-elevation site in south-central Montana. After 7 years, survival rates were similar, but growth rankings among provenances have changed. Trees must grow above the winter snow level for a few more years before the performance of each provenance can be clearly characterized.

KEYWORDS: provenances, seedlings, growth patterns, planting, lodgepole pine, *Pinus contorta*

Lodgepole pine (*Pinus contorta* var. *latifolia*) is often considered in the management of sites where its successional role (Pfister and Daubenmire 1975) is either dominant seral, persistent, or climax. Although lodgepole is the climax species on a relatively small area, it is a dominant seral or a persistent species over vast areas near and east of the Continental Divide in the United States and Canada. Here, stands are usually regenerated by clearcutting and artificial regeneration is sometimes required when natural regeneration fails. Natural regeneration sometimes fails when site scarification has been inadequate or logging and silvicultural activities have not been properly coordinated with the level of cone serotiny of the harvested stand.

When lodgepole pine must be artificially regenerated, a local seed source is commonly used. Perry's (1974) greenhouse experiments, however, have shown that 1-year-old lodgepole pine seedlings from Idaho, Washington, and British Columbia were taller and heavier than those from high-elevation sources in Montana and Utah, although little difference in response to day length and temperature differences was noted among the sources. And in British Columbia, studies of 144 provenances (Illingworth 1975) planted at coastal versus inland locations showed that growth was not correlated with proximity of seed source, but that early height growth and frost resistance differed among provenances. These studies suggested that geographical differences in productivity of stands might have a genetic component and that seedlings might be grown successfully in continental climes from seed gathered from a considerable distance if sufficiently adapted to cold.

Subsequent provenance studies have clearly shown that adaptation in lodgepole pine is closely related to environmental variables (Critchfield 1980; Rehfeldt and Wykoff 1981). Rehfeldt and Wykoff found that heritability for growth among 30 lodgepole pine populations of Idaho and Montana was expressed through adaptation of shoot elongation to the length of the growing season rather than temperatures alone of the widely different elevations tested. Correspondence of variation in shoot elongation with variation in freezing tolerance was interpreted as evidence that height growth of lodgepole pine seed sources is coordinated with cold acclimation through adaptation to the length of the growing season. More recently, Rehfeldt (1983) has qualified and quantified the adaptation potential of 28 northern Idaho lodgepole pine populations for cold hardiness and growth potential and has synthesized these negatively correlated traits into guidelines for determining seed transfer intervals for northern Idaho lodgepole pine populations.

Perry's tests—as well as the mild-environment tests of Illingworth and Rehfeldt/Wykoff—measured the innate growth potential of various lodgepole pine seed sources. On the basis of the greenhouse results of Perry and the availability of sibling seedlings from the same parent trees used by Perry, we decided to measure performance on a severe site: actual growth expression of Perry's five seed sources in a high-elevation Montana environment. This paper reports 7-year results of the study. Eventually, differences in growth patterns will be quantified in terms of timber productivity.

---

[1] Research forester and forester, respectively, located at Intermountain Station's Forestry Sciences Laboratory, Bozeman, Mont.

METHODS

Seeds were collected from 10 parent trees in each of five widely separated stands in Utah, Montana, Idaho, Washington, and British Columbia. Locations, latitudes, elevations, and site indexes of the stands are shown in table 1. Stands were selected from the *Abies lasiocarpa/ Pachistima myrsinites* habitat type or its ecological equivalent (Daubenmire and Daubenmire 1968) to represent, as much as possible, reasonably uniform growing conditions for lodgepole pine (Perry 1974).

Seeds were planted in 1972 at Lucky Peak Nursery, near Boise, Idaho, and lifted as 3-0 stock in the spring of 1975 for transplanting on the study site. The study area is located near Rat Lake—Squaw Creek drainage, Gallatin National Forest, Mont.—in a clearcut area harvested in 1970. Lodgepole pine was the major species in the overstory, with a small proportion of Engelmann spruce (*Picea engelmannii*) (Parry) distributed throughout the stand. Site index for lodgepole pine is 60 to 70 ft (18 to 21 m) at 100 years, and elevation is about 6,600 ft (2 000 m) above sea level.

The soil in the study area is a silt loam, developed to 18+ inches (46+ cm). The study area lies across a gentle draw midway up a gentle, north-facing slope. The site is quite moist into July in most years. No weather data are available for the immediate study area, but total annual precipitation recorded at the Squaw Creek Ranger Station, 4 mi (6.4 km) distant, averages 30 inches (76 cm). The ecological habitat type (Pfister and others 1977) is *Abies lasiocarpa/Linnaea borealis*. Prominent understory species at the time of harvest were *Linnaea borealis*, *Vaccinium caespitosum*, and *Calamagrostis canadensis*.

Seedlings were lifted from the nursery as 3-0 bareroot stock before spring growth began in 1975, bundled by parent tree identity, and placed in cold storage until the planting site was free of snow.

Two hundred and eighty-four seedling representing from 4 to 10 offspring of each parent tree were planted on June 9-10, 1975, in 13 rows of a 0.75-acre (0.3-ha) plot. Trees were spaced 10 ft (3 m) apart in the rows, and rows were spaced 10 ft (3 m) apart. Planting spots were grouped by parent tree—that is, all seedlings from a given parent tree were planted in consecutive planting spots of a row, but the row-location of a group of seedlings from a single parent tree in relation to those from another parent was random. It would have been desirable to completely randomize the experiment to the individual tree level; however, randomization of individual seedlings was foregone because it would have required increased handling and might have caused increased mortality and confounded survival and growth results.

Planted seedlings were staked and identified with tags showing the seed source, parent tree, and individual tree number of each seedling.

Mortality was recorded, and total height and annual height growth were measured in centimeters—in 1976, 1978, 1979, and 1982. Crown width, in centimeters, was added to the measurements in 1982.

Data were analyzed for differences in survival, crown width, total height, and periodic and annual height growth. The chi-square test was used to evaluate differences in survival rates. Because mortality differed significantly in the 1975-76 establishment period and could confound growth means, growth measurements for 1976 were not used to test growth differences among the provenances—with the exception of total tree height in 1976, which was used as a covariate in testing provenance differences in height growth after 1976. Crown width of the trees was also found to covary with their heights; therefore, height of trees in 1982 was used as a covariate in the analysis of variance of 1982 crown widths among provenances.

Table 1.—Location and site characteristics of stands providing seed for the provenance study

Stand	Location	Elevation		Habitat type	Site index (Alexander 1966)
		Feet	*(Meters)*		
Washington	Sherman Pass, Colville N.F., lat. 48°36′ N	5,250	(1 600)	Abies lasiocarpa - Pachistima myrsinites (Daubenmire and Daubenmire 1968)	90
Montana	Butte Meadows, Gallatin N.F., lat. 45°26′ N	7,220	(2 200)	Abies lasiocarpa - Galium triflorum (Pfister and others 1977)	80
Utah	Gilbert Creek, Wasatch N.F., lat. 40°54′ N	8,200-11,480	(2 500-3 500)	Abies lasiocarpa/Berberis repens and A. lasiocarpa/ Vaccinium scoparium (Pfister 1972)	45
Idaho	Little Slate Creek, Nezperce N.F., lat. 45°40′ N	5,100	(1 550)	Abies grandis - Xerophyllum tenax (Steele and others 1981)	90
British Columbia	Cariboo Land District, lat. 53°25′ N	2,300	(700)	Unknown, but probably Abies lasiocarpa -Clintonia uniflora (Daubenmire and Daubenmire 1968)	100

RESULTS

Survival

Survival rates of the provenances ranged from 77 to 90 percent in the first year and 74 to 88 percent in the seventh year after planting (table 2)— indicating that most of the mortality to date occurred in the first year. The chi-square value for differences in survival rate among the five provenances in 1976 was 9.97, while the appropriate table value of chi-square at the 0.05 level is 9.49; thus, we conclude that the differences among the survival rates of the provenances in the first year were significant at the 0.05 level. This is primarily due to the lower initial survival rate of the Idaho seedlings. The corresponding chi-square test of percentage of survival in 1982 ($\chi^2 = 7.87$), however, indicates that differences in survival among the provenances after 7 years are no longer significant.

Growth

Means and standard deviations of total heights, annual leader growth, and crown widths of trees are summarized in table 3 for provenances at each year of measurement. Results of covariance analysis of the four growth expressions used as response variables are discussed below.

Table 2.—Number of trees planted and percentage of trees surviving in 1976 and 1982, by provenance

Provenance	Trees planted 1975	Percent surviving 1976	1982
Utah	63	90	83
Montana	51	90	88
Washington	46	87	78
Idaho	43	77	74
British Columbia	81	88	84
Total and percentage means	284	86	81

Table 3.—Means and standard deviations (in parentheses) of heights, terminal leader lengths, and crown widths—by provenance and year of measurement

Provenance	Year	Total height	Terminal leader length	Crown width
		Centimeters		
Utah	1976	18.9 (9.2)	5.4 (3.2)	—
	1978	34.5 (11.4)	10.9 (4.6)	—
	1979	45.1 (15.3)	12.1 (5.7)	—
	1982	87.5 (27.5)	19.2 (7.7)	46.1 (18.2)
Montana	1976	18.7 (5.3)	5.7 (3.2)	—
	1978	36.8 (12.8)	11.0 (5.0)	—
	1979	48.4 (17.5)	12.9 (6.1)	—
	1982	93.8 (31.1)	21.5 (7.7)	53.3 (18.8)
Washington	1976	23.0 (7.4)	6.9 (4.8)	—
	1978	43.6 (15.2)	13.4 (5.2)	—
	1979	56.6 (19.9)	13.8 (5.7)	—
	1982	110.8 (38.9)	20.8 (10.5)	53.6 (18.6)
Idaho	1976	21.3 (8.3)	6.5 (4.0)	—
	1978	43.7 (15.9)	15.5 (5.9)	—
	1979	60.2 (19.6)	15.9 (5.6)	—
	1982	119.2 (35.8)	24.4 (9.8)	62.2 (19.0)
British Columbia	1976	27.2 (7.6)	7.8 (4.6)	—
	1978	56.0 (19.0)	17.6 (6.9)	—
	1979	72.5 (24.2)	18.3 (7.3)	—
	1982	133.4 (44.4)	24.4 (10.2)	69.7 (23.4)

CROWN WIDTH

Crown width in 1982 differed significantly (P = 0.015) among the provenances according to the overall F-test of mean crown widths adjusted for mean heights of the provenances in 1982. T-tests of all provenance comparisons (table 4), taken two at a time, revealed that 1982 crown widths, adjusted to a common height, were significantly greater (0.05 level) for Montana trees than those of Utah and Washington, while crown widths of trees from British Columbia were significantly greater than Washington trees. Crown width differences between the other provenances were not significant at the 0.05 level.

TOTAL HEIGHT

Total 1982 height differed significantly (P = 0.009) among provenances when means were adjusted for 1976 heights. Paired t-tests of adjusted total 1982 height means (table 4) for the 10 provenance combinations showed that Idaho and British Columbia trees were significantly greater (P = 0.05) than those of Montana and Utah. Adjusted heights of Washington trees were intermediate to the other provenances, but not significantly different from them. The 1982 heights were adjusted because British Columbia, Washington, and Idaho seedlings, although not measured, were observed to be taller than those of the other provenances at the time of planting. This was the same pattern of differences observed by Perry (1974) on progeny of the same parents after 1 year in a greenhouse.

PERIODIC HEIGHT GROWTH

Periodic height growth, 1976-82, demonstrated the same pattern as total heights, differing significantly among provenances (P = 0.009) when growth means were adjusted for heights in 1976. T-tests of the adjusted mean differences of all combinations of provenance comparisons, taken two at a time, showed that 6-year height growth of Idaho and British Columbia trees was significantly greater (0.05 level) than those of Utah and Montana (table 4). Washington trees were intermediate to, but not significantly different from, the other provenances.

CURRENT HEIGHT GROWTH

No significant statistical differences in current (1982) annual height growth were detected among provenances when means were adjusted for tree heights in 1976. Although the overall F-test of the adjusted provenance means of 1982 height growth (table 4) did not allow rejection of the null hypothesis, lack of significance on this test can be due to relatively large differences in the mean values of the covariate among the provenances (Snedecor and Cochran 1967), such that only very large provenance differences could be detected. The Newman-Keuls sequential test of ranked adjusted means was used to test against this possibility; however, the greatest difference in adjusted provenance means (Idaho versus Washington) was still not significant at the 0.05 level.

DISCUSSION

Early differences in survival and height growth, among the provenances studied here, appear to be changing. Survival rates have nearly equalized and total height-growth rankings have shifted from their earlier pattern. Remeasurement of the study 5 to 10 years hence will provide a better indication on whether differences will disappear or continue to change.

At this point, we believe that differences among the provenances will continue to develop and will be different in pattern than shown to date. We base this opinion on two facts: (1) the local (Montana) seed source has the highest crown width/height ratio at present, and has risen to second place in current annual adjusted height growth, compared to its fifth place ranking in total height 6 years earlier, and (2) seedlings and saplings have been covered and protected by deep winter snows, therefore, climate has yet to fully express its potentially discriminating effect on survival and growth. In the next 5 to 10 years, most of the trees will grow above the snow level and differences in provenance growth and survival then could indicate unsuitability of some provenances for planting on high elevation sites in Montana.

Table 4.—Covariance-adjusted provenance means of four growth expressions

Provenance	Mean 1982 crown width adjusted for mean 1982 height		Mean total 1982 height adjusted for mean 1976 height		Mean periodic height growth 1976-82, adjusted for 1976 height		Mean 1982 height inc ment adjusted for 19 height.	
	Inches	*(cm)*	*Inches*	*(cm)*	*Inches*	*(cm)*	*Inches*	*(cm)*
British Columbia	23.1	(58.6) ab[1]	46.5	(118.0) a	38.1	(96.8) a	8.7	(22.2)
Idaho	22.8	(57.8) abc	47.8	(121.4) a	39.1	(99.2) a	9.8	(24.8)
Washington	20.9	(53.2) c	42.2	(107.1) ab	33.4	(84.9) ab	8.0	(20.3)
Montana	24.0	(61.0) a	40.9	(103.9) b	32.2	(81.7) b	9.0	(22.9)
Utah	22.4	(56.8) bc	39.4	(100.1) b	30.1	(77.9) b	8.2	(20.7)

[1] Adjusted provenance means not sharing a common letter within a column are significantly different at the 0.05 level for that growth expression.

CONCLUSIONS

1. Seedlings from all provenances have been able to urvive for 7 years in this high-elevation Montana abitat, with no significant differences in survival rates mong provenances over the past several years. Nevertheless, this situation might change in the next few ears as all provenances grow above the winter snow evel of the site, thereby exposing the trees to greater limatic extremes. At that time, the survival rates of rees from some seed sources could be significantly educed.

2. Growth differences among provenances expressed in he 1-year greenhouse trials of Perry (1974) were luplicated in the first year of outplanting of siblings rom the same parents on this high-elevation site. But, atterns of 1982 height growth, relative to growth over he 7-year period, indicate that the Idaho and Montana eed sources are gaining on provenances that earlier surpassed them. This is probably due to inherent tolerance f winter and early spring climatic extremes that are ow coming into fuller expression as the trees grow oward and then protrude above the winter snow level. How this adaptation advantage translates to long-term erformance, relative to the other seed sources, can only e determined by continued study.

REFERENCES

Alexander, R. R. Site indexes for lodgepole pine, with corrections for stand density: instructions for field use. Res. Pap. RM-24. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 7 p.

Critchfield, W. Genetics of lodgepole pine. Res. Pap. WO-37. Washington, DC: U.S. Department of Agriculture, Forest Service; 1980. 57 p.

Daubenmire, R.; Daubenmire, J. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 80. Pullman, WA: Washington State University, Agricultural Experiment Station; 1968. 104 p.

Illingworth, K. Lodgepole pine provenance research and breeding in British Columbia. In: Baumgartner, D., ed. Management of lodgepole pine ecosystems: Symposium proceedings. Pullman, WA: Washington State University; 1975: 47-67.

Perry, D. A. Ecotypic variance in *Pinus contorta* var. *latifolia*. Bozeman, MT: Montana State University; 1974. 103 p. Ph.D. thesis.

Pfister, R. D. Vegetation and soils in the subalpine forests of Utah. Pullman, WA: Washington State University; 1972. 98 p. Ph.D. thesis.

Pfister, R. D.; Daubenmire, R. Ecology of lodgepole pine (*Pinus contorta* Dougl.). In: Baumgartner, D., ed. Management of lodgepole pine ecosystems: Symposium proceedings. Pullman, WA: Washington State University; 1975: 27-46.

Pfister, R. D.; Kovalchik, B.; Arno, S.; Presby, R. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Rehfeldt, G. E. Adaptation of *Pinus contorta* populations to heterogeneous environments in northern Idaho. Can. J. For. Res. 13: 405-411; 1983.

Rehfeldt, G.; Wykoff, W. Periodicity in shoot elongation among populations of *Pinus contorta* from the northern Rocky Mountains. Ann. Bot. 48: 371-377; 1981.

Snedecor, G.; Cochran, W. Statistical methods. 6th ed. Ames, IA: The Iowa State University Press; 1967. 593 p.

Steele, R.; Pfister, R.; Ryker, R.; Kittams, J. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 138 p.

ACKNOWLEDGMENTS

The authors are grateful for the assistance of several individuals in initiating and conducting this study. David A. Perry, Oregon State University, collected, extracted, and stratified the seed. Frank Morby, nurseryman, Intermountain Region, Forest Service, supervised the growing and lifting of the seedlings used in the study. Lloyd Harris, Bozeman Ranger District, Gallatin National Forest, assisted in the location of the study site and planting of the seedlings.

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 231 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.

Field programs and research work units of the Station are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with the University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
- Provo, Utah (in cooperation with Brigham Young University)
- Reno, Nevada (in cooperation with the University of Nevada)

U.S. GOVERNMENT PRINTING OFFICE: 1984—776-032/1064 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-341

July 1984

Needed: Guidelines for Defining Acceptable Advance Regeneration

Dennis E. Ferguson[1]

ABSTRACT

Advance regeneration is an important component in many stands scheduled for harvesting. Properly managed, such regeneration can contribute to a healthy, new stand, but too often trees do not quickly respond to the new environment or take too long to adjust. Definitions of acceptable advance regeneration are needed for pre- and postharvest inventories. The author discusses how to develop criteria for acceptable advance regeneration and guidelines for conducting inventories.

KEYWORDS: succession, Northern Rocky Mountains, reproduction, inventory

Advance regeneration becomes established naturally before the harvesting of a stand of mature timber. This regeneration can reduce the length of the next rotation and can reduce or eliminate costly site preparation and artificial regeneration efforts. Advance regeneration sometimes provides the species composition desired for the next rotation—species that may be difficult to regenerate subsequent to the harvest.

But advance growth can be relied on only if the trees respond well to release from overstory competition. Many things can prevent good response to release ncluding physiological shock, severe suppression, small root systems, small crowns, broken tops, stem scars, deformed boles, wrenched roots, and soil compaction.

Advance regeneration does not always quickly respond to overstory removal. Trees can remain stagnant too long, neither growing rapidly nor dying (fig. 1). Although minimum stocking requirements could be met by leaving advance regeneration and conducting a stocking

***Figure 1.**—Despite epicormic branching and 10 years time since release, this advance grand fir failed to respond well following overstory removal. This tree should not be included in determining if minimum stocking requirements have been met.*

---

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

inventory within a few years of the harvest, such an inventory would produce an erroneous picture of future forest productivity. Advance regeneration that is not capable of growing well after release or takes too long to adjust does not meet the intent the National Forest Management Act of 1976, State forestry practices acts, or minimum stocking standards adopted by private companies.

The inventory must provide detail about tree and stand conditions so that logical decisions can be made about future management of the stand. Areas that are potentially unproductive need to be identified as early as possible so that other methods can be scheduled to obtain healthy regeneration. Conversely, early identification of advance regeneration that will become a vigorous, new stand releases manpower and money for higher priority jobs.

Deciding which trees are cull and which should be kept is not easy because trees will range from obvious culls to high quality individuals. Nevertheless, these decisions must be made. The increasing emphasis of meeting specific stocking goals within a specified time demands that we define what is acceptable regeneration and what is not. Regeneration should no longer be tallied as being alive or dead, present or absent. Foresters need to consider a tree's condition and ability to grow well. This paper tells how to establish criteria for acceptable advance regeneration and provides guidelines for conducting inventories.

ADVANCE REGENERATION IN THE NORTHERN ROCKY MOUNTAINS

A substantial body of literature now shows that advance regeneration is a large component of stocking in recently harvested stands of the Northern Rocky Mountains. Six studies used a stratified random sample to retrospectively survey regeneration. Results vary by study location, site preparation, residual overstory density, the ecological community classification, and so on; however, they clearly show the potential management problem.

In 1975 and 1976 Ferguson, Stage, and Boyd (1984) sampled 4,964 1/300-acre plots in the grand fir-cedar-hemlock ecosystem of northern Idaho and adjacent portions of Montana and Washington. A wide range of overstory densities and site preparations was covered. Overall, 46 percent of all stocked plots had at least one advance conifer.

Seidel (1979) sampled mixed conifer clearcuts in the Blue Mountains of northeastern Oregon in 1976 and 1977. Here advance regeneration did not play a very important role because site preparation was thorough. Nevertheless, advance regeneration was present on 11 percent of the stocked milacre plots.

Carlson (1984) surveyed regeneration cuts in the western half of Montana during 1979-82. A total of 2,981 1/300-acre plots were sampled over a wide range of ecological and silvicultural conditions. At least one advance tree was present on 40 percent of stocked plots.

Ferguson (1984), sampling in central Idaho in 1979-82, used the same study design as Ferguson, Stage, and Boyd (1984). From 2,032 1/300-acre plots on the Payette and Boise National Forests, 40 percent of 716 stocked plots had at least one advance conifer present.

Seidel and Head (1983) sampled mixed conifer partial cuttings in the Blue Mountains of Oregon and Washington during 1980 and 1981. Advance regeneration comprised 20 percent of the total number of seedlings. Based on milacre stocking, advance regeneration was present on about one-third of stocked plots.

Dolezal (1982) sampled partial cuts in northeastern Oregon and central Washington in 1981. A total of 797 1/300-acre plots were installed. Advance grand fir (*Abies grandis*) was present on 41 percent of stocked plots, advance lodgepole pine (*Pinus contorta*) present on 14 percent of stocked plots, and advance Douglas-fir (*Pseudotsuga menziesii*) present on 13 percent of stocked plots. More than one advance tree species could occur on the same plot, so the percentages are not additive.

In a seventh study that did not use random stand selection, Smith and Wass (1976) looked at 9,361 milacre plots in clearcuts during 1974 and 1975. The study area was the Nelson Forest District of British Columbia. Unburned plots between roads had 77 percent advance regeneration on stocked plots. Burned plots had 28 percent advance regeneration on stocked plots.

INVENTORY CONSIDERATIONS

At least three inventories should be taken during the course of releasing advance regeneration. The first, and most important, is a preharvest inventory (fig. 2). Here the amount and condition of advance growth can be assessed. This inventory provides clues to postharvest response.

A second inventory should follow the harvest by a few years. The number of surviving trees will be important. Logging damage can also be assessed along with early indicators of growth response.

The third inventory is recommended to check the growth rate of released trees about 5 to 10 years after the harvest (fig. 3). Some trees may again become suppressed, this time by shrubs or undesirable tree species.

The key to defining acceptable advance regeneration is to integrate commonsense forestry and research findings into the inventory design. Guidelines may be needed for various geographic regions and ownerships due to differences in ownership goals, growing conditions, species of interest, and so on. Responses of released trees are described in research publications for both the United States and Canada. Table 1 summarizes research findings on releasing advance regeneration in the Northern Rocky Mountain area. Gravelle (1977) reviews current literature on the subjects of response to release, logging damage, and decay incidence, much of it pertaining to species in the Northern Rocky Mountains. Other literature is available on regeneration systems, logging damage, physiology of released trees, disease and insect considerations, and other species or geographic areas.

Johnstone, W. D. Growth of fir and spruce advance growth and logging residuals following logging in west-central Alberta. Information Report NOR-X-203. Edmonton, Alberta, Canada: Canadian Forestry Service, Northern Forest Research Centre; 1978. 16 p.

McCaughey, Ward W.; Schmidt, Wyman C. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. Research Paper INT-285. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 19 p.

Seidel, K. W. Suppressed grand fir and Shasta red fir respond well to release. Research Note PNW-288. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 7 p.

Seidel, K. W. Regeneration in mixed conifer clearcuts in the Cascade Range and the Blue Mountains of eastern Oregon. Research Paper PNW-248. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 24 p.

Seidel, K. W. Diameter and height growth of suppressed grand fir saplings after overstory removal. Research Paper PNW-275. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980a. 9 p.

Seidel, K. W. A guide for comparing height growth of advance reproduction and planted seedlings. Research Note PNW-360. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980b. 6 p.

Seidel, Kenneth W. Growth of suppressed grand fir and Shasta red fir in central Oregon after release and thinning—10-year results. Research Note PNW-404. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 7 p.

Seidel, K. W.; Head, S. Conrade. Regeneration in mixed conifer partial cuttings in the Blue Mountains of Oregon and Washington. Research Paper PNW-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 14 p.

Smith, R. B.; Wass, E. F. Soil disturbance, vegetative cover and regeneration on clearcuts in the Nelson Forest District, British Columbia. BC-X-151. Victoria, B.C. Canada: Canadian Forestry Service, Pacific Forest Research Centre; 1976. 37 p.

6. Age. Older trees may not respond as well as younger trees, depending on species, growing conditions, and height at release. Some trees beyond a certain age should be culled simply because they may be infected with dormant rot fungi.

7. Height increment before release. Generally, a tree growing well before release should respond well to overstory removal. Height increment prior to release is an indication of the degree of suppression.

8. Relationship between total tree height and height increment. Tall trees with small height increments may be poorer candidates for release than shorter trees having the same height increment.

Postharvest Inventories:

1. Height growth following release. This variable shows how each tree is responding to release. Species with preformed shoots probably have an additional 1-year lag in responding to release. See Ferguson and Adams (1980) for a more detailed discussion concerning preformed shoots and released trees.
2. Logging damage. A tree injured during logging can suffer a broken top, stem scars, bole deformities, severe lean, wrenched roots, and soil compaction around the roots. If the soil is compacted, the roots of released trees will have difficulty expanding. Root rots are also a possibility.
3. Numbers of surviving trees of desirable species.
4. Appearance.
5. Crown ratio.
6. Needle color or needle length.
7. Finally, consider the alternatives. If the stand has been harvested and advance trees are responding slowly, would other regeneration alternatives be expected to do better? Advance regeneration does provide stocking, and perhaps a 5- or 10-year delay in response by advance regeneration is preferable to low probabilities of obtaining stocking by natural or artificial regeneration. (Early identification of this potential problem is why the preharvest inventory is so important.)

After listing variables, choose those of most importance. If possible, select those easiest to use in the field and those that are the least subjective. For example, it is easier and less subjective to measure height increment following release than it is to judge whether a tree will live or die in the next 50 years.

Finally, field crews must be provided with guidelines for inventorying regeneration. Regeneration not meeting minimum standards can still be tallied as long as the crew identifies such trees as culls. Be as specific as possible, especially for subjective decisions. If crews record variables that can be measured directly in the field, minimum standards can be changed after the inventory is completed. For example, suppose that for each tree the 5-year height increment before release was recorded. A minimum standard of 1.0 foot would result in a certain inventory of trees. Should it be desirable to change this minimum increment to 1.5 feet, the inventory could be recompiled in the office.

The inventory guidelines could also be put to other uses. Some of the guidelines might be applied to subsequent regeneration or they might be helpful in choosing leave trees in precommercial thinnings.

Whether the land manager is dealing with Federal, State, corporate, or private land matters little—the goal of a regeneration harvest is a vigorous new stand. Advance regeneration can help achieve such a stand. By developing standards for acceptable advance regeneration and guidelines to aid field crews conducting regeneration surveys, foresters will insure that they are meeting the intent of the National Forest Management Act, State forestry practices acts, and corporate or private ownership goals.

REFERENCES

Carlson, Clinton E. Study on the susceptibility and vulnerability of northern Rocky Mountain Forests to the western spruce budworm. 1984. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Missoula, MT.

Dolezal, Sharon M. Natural regeneration establishment models for northeastern Oregon and central Washington. Moscow, ID: University of Idaho; 1982. 116 p. M.S. thesis.

Ferguson, Dennis E. Study on the effects of spruce budworm on regeneration success in Idaho's forest ecosystems. 1984. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Moscow, ID.

Ferguson, Dennis E.; Adams, David L. Response of advance grand fir regeneration to overstory removal in northern Idaho. Forest Science. 26(4): 537-545; 1980.

Ferguson, Dennis E.; Stage, Albert R.; Boyd, Raymond J. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the Northern Rocky Mountains. Moscow, ID: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 82 p. Review draft.

Frisque, Gilles; Weetman, G. F.; Clemmer, E. Reproduction and trial projected yields 10 years after cutting 36 pulpwood stands in eastern Canada. Technical Report TR-23. Vancouver, B.C., Canada: Forest Engineering Research Institute of Canada; 1978. 63 p.

Gravelle, Paul. Growth response and logging damage to advanced regeneration following overstory removal: the present state of knowledge. Forestry Technical Paper TP-77-3. Lewiston, ID: Potlatch Corporation; 1977. 26 p.

Herring, L. J. Studies of advance subalpine fir in the Kamloops Forest District. Research Note No. 80. Victoria, B.C., Canada: Province of British Columbia, Forest Service Research Division; 1977. 22 p.

Herring, L. J.; McMinn, R. G. Natural and advance regeneration of Engelmann spruce and subalpine fir compared 21 years after site treatment. The Forestry Chronicle. 56(2): 55-57; 1980.

igure 2.—Preharvest inventories should ndicate the amount and condition of dvance regeneration. This inventory is mportant in predicting response following arvest.

able 1.—Selected readings on releasing advance regeneration in the Northern Rocky Mountain area

eference	Study location	Study species
erguson and dams 1980	northern Idaho	*Abies grandis*
erring 1977	interior British Columbia, Canada	*Abies lasiocarpa*
erring and cMinn 1980	interior British Columbia, Canada	*Abies lasiocarpa,* *Picea engelmannii*
ohnstone 1978	west-central Alberta, Canada	*Abies lasiocarpa,* *Picea glauca,* *Picea mariana*
cCaughey and chmidt 1982	central Idaho, Utah, northwestern Wyoming	*Abies lasiocarpa,* *Picea engelmannii*
eidel 1977	central Oregon	*Abies grandis,* *Abies magnifica*
eidel 1980a	central Oregon	*Abies grandis*
eidel 1980b	n.a.	n.a.
eidel 1983	central Oregon	*Abies grandis,* *Abies magnifica*

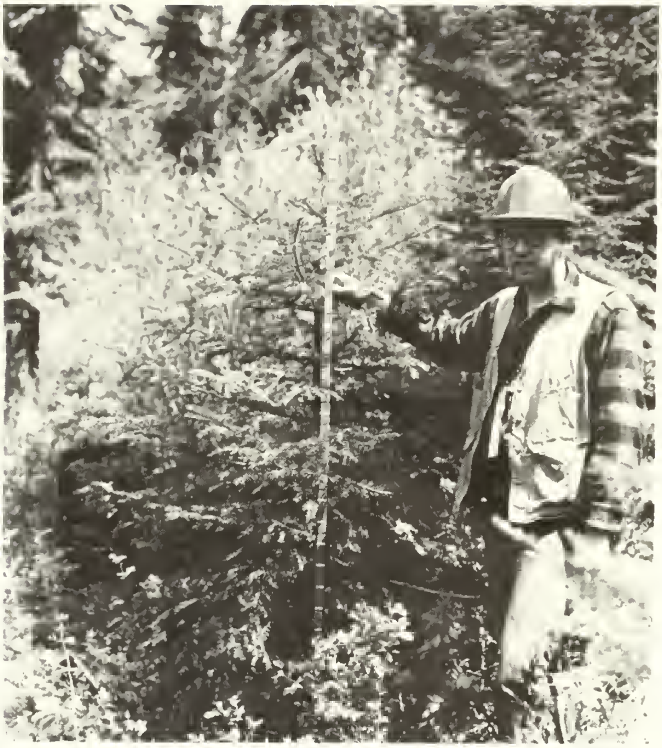


Figure 3.— *The inventory design or instructions to field crews provide the basis for deciding the fate of advance regeneration. Field crews can be trained to make the decision in the field, or to record the tree and site characteristics that lead to a decision in the office.*

Begin by reading pertinent literature and compiling a list of variables that may be important in deciding which trees to keep. Frisque, Weetman, and Clemmer (1978) provided the following list of criteria to define "best specimen" trees on milacre plots:

"a) live more than 50 years,
b) be adapted to the site,
c) be one of the tallest . . . ,
d) not have any disease, breakage, or insects,
e) have no obviously defective root system, and finally,
f) be of a species able to form naturally more than 25% of an adult stand."

Some other potentially important factors to consider are as follows:

Preharvest Inventories:

1. Number of trees. Large numbers of advance regeneration increase the odds that a sufficient number will respond to release.
2. Species. Some species may be more desirable than others, depending on site suitability, commercial value, insect/disease problems, and so on.
3. Healthy and vigorous appearance.
4. Crown ratio.
5. Needle color or needle length.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (In cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-342

September 1984

Heat of Preignition of Three Woody Fuels Used in Wildfire Modeling Research

Ronald A. Susott[1]

ABSTRACT

Differential scanning calorimetry has been applied to three woody laboratory fuels studied in current wildland fire modeling research. The heat required to increase a fuel's temperature to ignition is an important modeling parameter affecting the rate of fire spread. Below 200° C, ground fuel-stick samples had similar heat requirements, but above 200° C the heat of preignition varied up to 19 percent among fuels. Therefore, these variations can affect fire spread rates similarly to variations in moisture content. A consistent set of data is provided for calculating the heat of preignition. Thermogravimetric analysis data are included to allow mass balance calculations.

KEYWORDS: specific heat capacity, pyrolysis, thermogravimetric analysis, fire models

Mathematical fire behavior models require the fuel preignition heat (Q_{ig}) as an input parameter (Rothermel 1972; Wilson 1982). This parameter is the total heat required to raise the temperature of unit mass of fuel to the ignition temperature. An ignition temperature of about 320° C is usually assumed. Frandsen (1973) describes a method for calculating Q_{ig} by integrating, over temperature, the specific heat capacities (C_p) of dry fuel and fuel moisture, and adding the heat of vaporization of moisture. Moisture's contribution to Q_{ig} has been assumed to be independent of the fuel burned.

The specific heat capacity of dry fuel, C_p (fuel), is a variable that depends on fuel composition. In general, C_p (fuel) should be determined for each fuel of interest, but in practice the equation for wood reported by Dunlap (1912),

$$C_p\ (\text{average}) = 1.11 + 0.00486T \qquad (1)$$

has been used as an average value. C_p is the specific heat capacity (J/°C · g) and T is temperature (°C). This equation is expected to represent wood below 150° C, but may result in considerable error at higher temperatures where C_p data are not available. Heat capacity equations do not apply above the onset of thermal degradation where loss of products begins, but these higher temperature heat requirements are essential to fire behavior modeling.

Differential scanning calorimetry (DSC) has recently been applied to several fuels of interest to forest fire modelers (Susott 1982). That report provided a consistent set of Q_{ig} and weight loss data for packing excelsior (*Populus* spp.), ponderosa pine heartwood (*Pinus ponderosa* Laws.) from ½-inch (12.7-mm) lumber, and Douglas-fir (*Pseudotsuga menzeisii* [Mirb.] Franco) wood from ⅛-inch (3.2-mm) veneer, along with data on three samples of conifer needles and a sample of rotten Douglas-fir wood. The burning characteristics of the first three woody materials have been extensively studied to develop fire behavior models.

Current studies are aimed at extending fire behavior models to a wider range of fuel size, bed depth, packing ratio, and moisture content. These studies have added 1/16-inch (1.6-mm) sugar pine (*Pinus lambertiana* Dougl.) sticks and 1½-inch (38.1-mm) lumber of mixed species (mostly pine and fir) to the list of materials extensively burned. Q_{ig} data are not available on these latter two fuels nor on the ¼-inch (6.4-mm) ponderosa pine fuels burned for Rothermel's original study (1972) and Wilson's current study (1982).

The objective of this note is to provide complete Q_{ig} and weight loss data on the 1/16-, ¼-, and 1½-inch fuels used in fire behavior tests. Accurate data on Q_{ig} will allow a more detailed evaluation of relationships between other model parameters such as fuel bed depth, surface area-to-volume ratio, packing ratio, and moisture content. More complete data will also allow evaluation of new theories of how the heat sink characteristics affect fire behavior.

EXPERIMENTAL METHODS

Sample preparation.—The three wood samples were taken from lumber supplies used extensively for fire modeling (Rothermel 1972; Wilson 1982) at the Northern Forest Fire Laboratory. Small sections of

---

[1] Research chemist stationed at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Mont.

about 100 sticks were taken at random, ground to finer than 20 mesh, and combined into one homogeneous sample of each fuel type (sizes 1/16-, 1/4-, and 1 1/2-inch).

Differential Scanning Calorimetry (DSC).—The DSC method used in this study has been described elsewhere (Susott 1982). The use of a microcomputer/controller facilitated the exact replication of the experimental method. Part of the value of these data is that they form a consistent set, obtained under identical experimental conditions, and should provide valid comparisons between fuels. As before, a 10-mg fuel sample was heated at 20° C/min in a 200 ml/min nitrogen purge. Four replicate runs were averaged for the final result.

A sapphire standard was used to calibrate the DSC heat flow rate. Data from four standard runs were combined and analyzed by polynomial regression resulting in the equation

$$E = 219.9 + 0.01489T + 0.000444T^2 \qquad (2)$$

where E is the DSC calibration coefficient (mW/V) and T is temperature (° C). The coefficient of determination, r^2, was 0.981. Equation 2 is in agreement with the previously reported calibration (Susott 1982) to within 2 percent over the range from 50° to 500° C. As before, all calibration runs were within 5 percent of equation 2. The accuracy of fuel sample measurements is expected to be within better than 5 percent.

Thermogravimetry (TG).—The experimental method used for TG has been described elsewhere (Susott 1980). Two runs at 20°/min were averaged and replicate runs generally agreed to within 1 percent. Sample size and thermal treatment were the same as for DSC runs.

Moisture contents were measured from the TG curves as weight loss at 140° C. TG and DSC data were calculated on a dry weight basis.

The time derivative of the TG curve (DTG) was calculated numerically as reported previously (Susott 1982).

RESULTS AND DISCUSSION

Figures 1, 2, and 3 show the DSC curves for ground samples from 1/4-inch ponderosa pine sticks, 1/16-inch sugar pine sticks, and the 1 1/2-inch sticks of mill-run pine and fir, respectively. (Endothermic effects cause a positive DSC output.) The DTG curves are superimposed on the DSC to indicate weight losses once moisture is driven off. Both curves are based on dry sample weight.

The DSC curves were very similar among these three wood samples, as were the DTG curves. They are also qualitatively similar to the three sound wood samples (packing excelsior, 1/8-inch Douglas-fir wood, and 1/2-inch ponderosa pine heartwood) previously reported (Susott 1982). All samples showed the linear increase in C_p , predicted by equation 1, at least up to 200° C. (The small peak at 40° C is a measurement transient due to the start of heating.) The C_p values below 200° C shown in figures 1 to 3 are 5 to 10 percent lower than equation 1, but agree more closely with values given by Koch (1969) for spruce pine (*Pinus glabra* Walt.) wood. DTG curves show that pyrolytic weight loss begins in this region. The pyrolysis rate increases above 250° C, causing an exothermic peak at 325° C but changing to a sharp endothermic peak between 350° and 400° C. Above 400° C, the weight

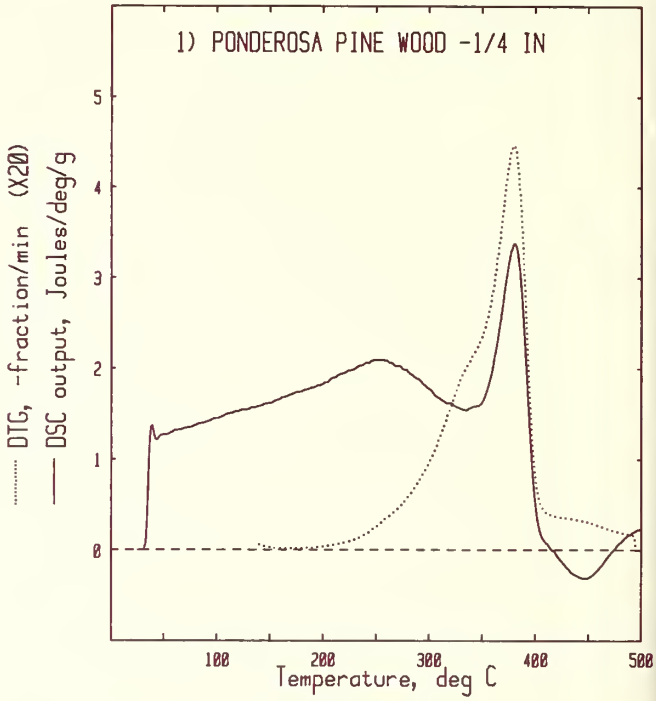


Figure 1. — DSC and DTG curves for ground ponderosa pine wood from 1/4-inch sticks.

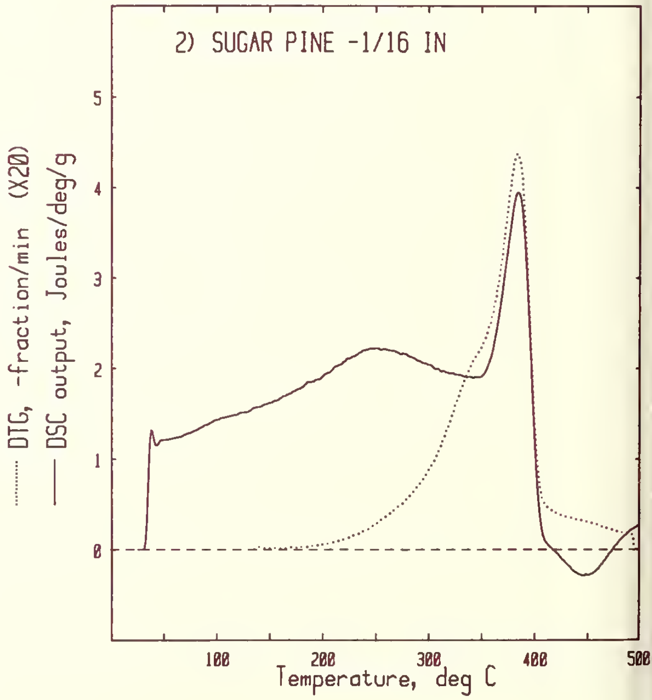
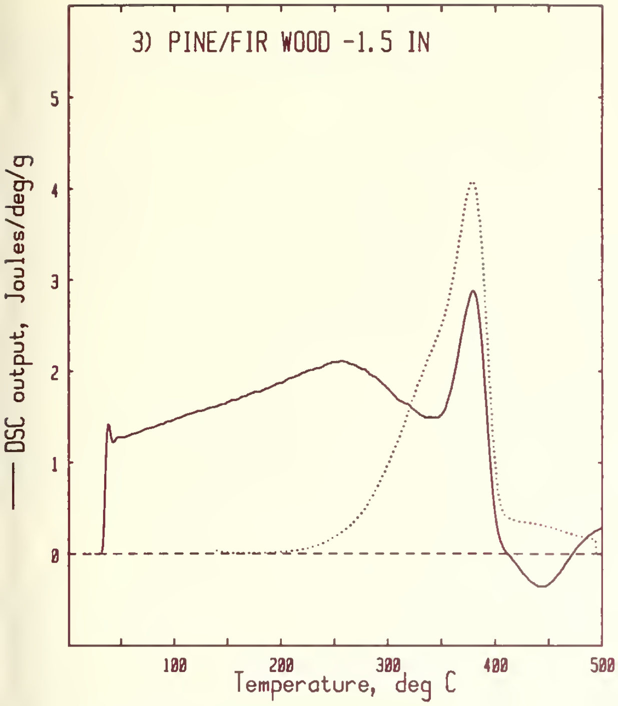


Figure 2. — DSC and DTG curves for ground sugar pine wood from 1/16-inch sticks.



ure 3. — DSC and DTG curves for ground od of mixed species (mostly pine and fir) from -inch sticks.

s rate abruptly decreases and the DSC shows a broad othermic peak at 425° C.

Quantitative comparisons are best made with the egrated DSC results in table 1. Table 2 gives the G mass fraction remaining at temperatures above 140° following the moisture loss. Below 200° C, where dominates the DSC curve, the total heat requirement eraged 270 ± 7 J/g for six woody fuels (three in s study combined with 271, 281, and 276 J/g from : woody fuels analyzed in the previous report). Equ- ons given by Koch (1969) predict a value of 277 J/g ' the integral from 25° to 200° C. This good agreement rifies the DSC calibration at low temperatures, and nfirms that a constant contribution to Q_{ig} can be sumed for the wood samples analyzed. The value for -inch sugar pine was significantly lower than for ½- ch pine (5 percent level), but the difference was only out 7 percent. Within experimental error (about 5 rcent), the wood samples used in combustion tests Rothermel (1972) and Wilson (1982) have the same ecific heat capacity up to 200° C.

These samples show larger differences in the DSC egral from 200° to 400° C. At 400° the 1½-inch cks gave the lowest value of 649 J/g, compared to 2 J/g for 1/16-inch sugar pine, and 781 J/g for ⅛-inch uglas-fir veneer in the previous report (Susott 1982). ese differences were significant at the 5 percent vel, showing a range of about 19 percent in the heat preignition at 400° C. This range is comparable to : effect of a 5 percent range in moisture content.

Table 1.—Integral of DSC results (J/g) at temperatures up to 500° C

Temperature	**Sample number** **1**	**2**	**3**
°C			
25	0	0	0
30	7	6	7
40	20	19	20
50	32	31	33
60	45	43	46
70	59	55	59
80	72	68	73
90	86	82	87
100	101	96	101
110	115	111	116
120	130	125	132
130	146	141	147
140	162	156	163
150	178	172	180
160	194	189	197
170	211	206	214
180	229	224	232
190	246	242	250
200	264	261	268
210	283	280	287
220	302	301	307
230	322	322	327
240	343	344	347
250	363	366	368
260	384	388	389
270	405	410	410
280	425	432	430
290	444	453	450
300	462	473	468
310	479	494	485
320	496	513	502
330	511	533	518
340	527	552	533
350	543	571	548
360	561	591	564
370	585	617	586
380	617	651	614
390	646	689	639
400	659	712	649
410	661	716	651
420	661	717	650
430	659	716	648
440	657	714	645
450	654	711	642
460	651	708	639
470	650	707	638
480	650	708	638
490	652	709	640
500	654	712	643

Note: Values are on a dry-weight, ash-included basis.
Integration from 25° to 40° C used dQ/dT at 40° C.
Samples: (1) Ponderosa pine wood, ¼-inch.
(2) Sugar pine, 1/16-inch.
(3) Pine/fir wood, 1½-inch.

Table 2.—TG weight (fraction remaining) at temperatures up to 500° C

Temperature	Sample number 1	2	3
°C			
140	1.000	1.000	1.000
150	.999	1.000	.999
160	.998	.999	.999
170	.998	.999	.999
180	.997	.998	.999
190	.997	.997	.998
200	.996	.996	.998
210	.995	.994	.997
220	.993	.991	.996
230	.990	.988	.994
240	.987	.983	.992
250	.981	.977	.988
260	.973	.968	.982
270	.963	.958	.974
280	.950	.945	.963
290	.934	.929	.947
300	.913	.909	.926
310	.885	.884	.898
320	.850	.853	.863
330	.807	.813	.819
340	.757	.766	.768
350	.701	.712	.709
360	.637	.652	.642
370	.556	.580	.559
380	.451	.486	.461
390	.352	.379	.369
400	.308	.313	.322
410	.295	.294	.307
420	.285	.283	.297
430	.276	.273	.288
440	.268	.264	.280
450	.260	.256	.272
460	.253	.249	.265
470	.246	.242	.259
480	.241	.237	.253
490	.237	.233	.249
500	.233	.228	.245

Note: Values are on a dry-weight, ash-included basis.
Samples: (1) Ponderosa pine wood, ¼-inch.
(2) Sugar pine, ¹⁄₁₆-inch.
(3) Pine/fir wood, 1½-inch.

CONCLUSIONS

Differential scanning calorimetry of six woody fuels gave good agreement in heat required for preignition below 200° C. Above 200° C, there is considerably more variation among fuels, especially from 300° to 400° C. These higher temperature contributions are not currently considered in modeling heat sink properties, but may be found necessary in new, improved fire models. The consistent set of data published herein allows evaluation of the effects of surface area-to-volum ratio and other variables on fire behavior in wooden cribs without the complication of an unknown Q_{ig} . Data on more fuel types are needed to extend these models to include other wildland fuels such as grasses, foliage, small twigs, and bark. We are working on improving the accuracy of the DSC method to provide these data.

REFERENCES

Dunlap, Frederick. The specific heat of wood. Bulleti 110. Washington, DC: U.S. Department of Agriculture, Forest Service; 1912. 28 p. Forest Products Laboratory (Madison, WI) series.

Frandsen, William H. Effective heating of fuel ahead of spreading fire. Research Paper INT-140. Ogden, UT: U.S. Department of Agriculture, Forest Servic Intermountain Forest and Range Experiment Station 1973. 16 p.

Koch, Peter. Specific heat of ovendry spruce pine woo and bark. Wood Science. 1: 203-214; 1969.

Rothermel, Richard C. A mathematical model for predicting fire spread in wildland fuels. Research Pape INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Ran Experiment Station; 1972. 40 p.

Susott, R. A. Effect of heating rate on char yield fro forest fuels. Research Note INT-295. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station 1980. 9 p.

Susott, Ronald A. Differential scanning calorimetry o forest fuels. Forest Science. 28(4): 839-851; 1982.

Wilson, Ralph A. A reexamination of fire spread in free-burning porous fuel beds. Research Paper INT 289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Ex periment Station; 1982. 28 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-0-776-032/10,505

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-343

September 1984

Resistance to *Cronartium ribicola* in *Pinus monticola:* Higher Survival of Infected Trees

R. J. Hoff[1]

ABSTRACT

A small percentage (1.5 percent) of seedlings cankered as a result of artificial inoculation in the early 1950's were still alive and cankered in 1981. The artificial inoculations were part of the original blister rust resistance progeny tests of western white pine. In a later test of this trait (called "higher survival"), families in three crossing groups, involving a total of 101 western white pine parent trees, accounted for about 25 percent of the variation.

KEYWORDS: blister rust, cankers, horizontal resistance, western white pine, higher survival resistance

Western white pine (*Pinus monticola* Dougl.) has several defense mechanisms to ward off attack by blister rust (caused by *Cronartium ribicola* J.C. Fisch. ex Rabenh.) (Bingham and others 1971; Hoff and McDonald 1980). Several appear to be inherited as single genes and result in elimination of the rust. Others are more complex in their action, conferring a more tolerant type of reaction. One such reaction is observed as higher survival of cankered seedlings. Usually the rust will quickly girdle a susceptible stem of a seedling or small tree resulting in death within a year or two—depending on the size of the tree. But a small percentage of trees do not readily die even though the rust has completely girdled the tree.

In a comparison of several white pine species from around the world Hoff and others (1980) found that the North American species rated highest for "alive and cankered" resistance. Although this is probably an artifact because high levels of "immune" resistance of the Eurasian species greatly decreased the number of seedlings in the test, it does show the existence of this kind of resistance in all white pines.

The purpose of this paper is to describe this defense mechanism and to present data relative to its inheritance in western white pine.

MATERIALS AND METHODS

Data presented here came from two sources. One set of materials was the original blister rust resistant progeny tests for western white pine established by R. T. Bingham during the early 1950's. The seedlings of three progeny tests were inoculated with blister rust after their second growing season and outplanted the following spring at three forest sites. Development of the rust infections was followed for several years by Bingham and others (1960). Most of the trees that had no infections were considered resistant to blister rust and were transplanted to a breeding arboretum in spring 1957. Of 4,835 trees in the original test, 214 were without basal cankers and 58 with basal cankers in fall 1981. Data were taken on tree height, diameter at breast height, and size of canker at its widest point (which was almost always at the ground line) expressed as a percentage of the circumference of the tree at that point.

The second set of data came from a much larger progeny test over a broader geographic area that nearly covered the entire inland range of western white pine south of the Canada-United States border. As in the first test, parent trees were selected for their apparent phenotypic resistance to blister rust. Ten control collections from squirrel caches or from rust-infected trees were included. These came from the major rust-resistance selection areas.

The mating design followed the factorial design of experiment II in Comstock and Robinson (1952). Progeny were planted in a randomized complete-block design. Each cross was represented by a 16-seedling plot in each of six blocks.

---

[1] Plant geneticist/Project Leader located at the Intermountain Station's Forestry Sciences Laboratory, Moscow, Idaho.

Data were based on the performance of progenies from three groups. Each group had four different males crossed with 51 female trees in group I, 21 in group II, and 17 in group III. The reciprocal cross was made if the female did not have enough flowers (at least five cones per pollen parent). Because previously unpublished work at the Intermountain Station indicated no reciprocal or maternal effects, the data were analyzed without regard to pollen or seed parent.

Test seedlings were inoculated in September, after their second growing season, under conditions outlined by Bingham (1972). The inoculum was obtained from heavily infected leaves of *Ribes hudsonianum* var. *petiolare* Dougl. Jancz. growing along the west fork of Hobo Creek northeast of Clarkia, Shoshone County, Idaho.

Rust inspection was completed as described by Hoff and McDonald (1980). Briefly, the following data were collected: (1) 9 months after inoculation—presence of needle spots; (2) 12 months after inoculation—presence of needle spots and stem symptoms (normal cankers plus bark reactions); (3) 24, 36, and 48 months after inoculation—presence of stem symptoms.

The number of seedlings that were alive and cankered 4 years after inoculation divided by the total number of cankered seedlings comprised the basic data. This percentage value is a measure of the ability of the seedlings from a family to survive with a stem canker.

The statistical model assumes that the males and females were random samples from the resistant tree populations. This is probably valid for all trees except group I males. These males had been selected for higher-than-average rust resistance from a previous test. However, they were selected only for their resistance due to the immune-type resistance, which is usually the result of single genes, so they were likely to be random selections for the survival trait that resembles the polygenic-type resistance found in agronomic systems (Nelson 1978).

The method of analysis followed that of Bingham and others (1969), Becker (1971), and Becker and Marsden (1972).

Because plot means ranged from 0 to 45 percent, they were transformed ($\arcsin \sqrt{\text{percent}}$) (Steel and Torrie 1960). There were 106 missing values for group I, 25 for group II, and 36 for group III. Because of the time and expense involved in estimating this many missing values, the analyses were completed without them. This provides data on the general variance of this trait. But there were too many missing values to permit reasonable estimates of variance components and heritabilities (9 percent were missing for group I, 5 percent for group II, and 9 percent for group III).

RESULTS

Of 3,762 seedlings that had stem cankers in the original progeny tests, 58 trees were still alive in fall 1981, nearly 30 years after inoculation (table 1). The basal cankers were relatively large (fig. 1, table 2), and many appeared to be very active as denoted by pitchiness (figs. 1-5) and sometimes with the typical yellow-orange margins (fig. 1). An average of 55 percent of the circumference of the infected trees was taken up by the canker (table 2). This ranged from 14 to 100 percent resulting in much deformity (fig. 5).

Average heights and diameters for trees with basal cankers were 42 ft (12.8 m) tall and 7 inches (18 cm) diameter. Averages for uncankered trees were 43 ft (13.1 m) tall and 7 inches (18 cm) diameter (table 2). The basal canker of the tree in figure 5 had grown 90 percent around the trunk and yet the tree was 48 ft (14.6 m) tall with a healthy looking crown **(fig. 6).**

Figure 1.—Large basal canker showing pitching and typical yellow margin (at arrow).

Table 1.—Number of trees with basal cankers; number of trees on the plot, fall 1981; and number of trees inoculated and planted

Test	Years following inoculation	Total trees planted	Trees with cankers	Surviving trees fall 1981	Trees with basal cankers	Trees with basal cankers
		Number				Percent
1	30	2,324	1,872	24	11	0.6
2	28	953	738	26	12	1.6
3	27	1,558	1,152	164	35	3.0
	Total	4,835	3,762	214	58	1.6

Figure 2.—Large basal canker with a large amount of pitch.

Figure 4.—Small basal canker with some pitching.

Figure 3.—Moderate-sized basal canker with pitch exuding from it.

Figure 5.—Largest basal canker in the plot, showing the amount of horizontal and vertical growth.

Data from the factorial crossing groups are summarized in table 3. Of 13,490 cankered seedlings, 1,686 (12.5 percent) were alive 4 years after inoculation. This ranged from 2.9 to 28.6 percent for individual families. Controls averaged 9.5 percent alive and infected, with a range of 3.2 to 23.8 percent.

Families accounted for about 25 percent (R^2 for the three groups was 0.28, 0.31, and 0.18) of the variation (table 4). Males for group I and females for groups I and II were significantly different at the 1 percent level of probability (SAS 1982).

Figure 6.—Tree marked with arrow is the same tree as shown in figure 5. It is 48 ft (14.6 m) tall and has a healthy crown.

Table 2.—Mean height, diameter at breast height, and percentage of circumference of basal canker in fall 1981

Progeny test year	Trees with no basal cankers		Trees with basal cankers			
	Height	d.b.h.[1]	Height	d.b.h.	Size of canker	Range
	Ft (m)	*Inches (cm)*	*Ft (m)*	*Inches (cm)*	*Percent*[2]	*Percent*
52	46 (14.1)	7 (18)	44 (13.4)	9 (23)	59	27-85
54	47 (14.2)	7 (18)	47 (14.3)	8 (20)	57	14-80
55	37 (11.3)	7 (18)	36 (11.0)	5 (13)	50	14-100
X	43 (13.1)	7 (18)	42 (12.8)	7 (18)	55	18-88

[1] Diameter at breast height (4.5 ft/1.4 m).

[2] Proportion of tree circumference encircled by canker at widest point of canker.

Table 3.—Average number of seedlings per plot and average percentage that were still alive and cankered 4 years after inoculation, for three crossing groups

			Crossing groups		
			I	II	III
Seedlings (living and dead) with cankers			7,271	3,905	2,314
Average seedlings per plot			6.50	8.15	5.73
Average percentage living					
		a.	22.2	12.3	11.4
	Males	b.	7.5	11.3	8.4
		c.	9.7	11.4	16.9
		d.	11.9	9.2	12.7
Average			13.01	11.1	13.1
Range of females			6.5 - 28.6	2.9 - 26.7	7.8 - 20.2
Controls 9.5 percent alive, range 3.2 - 23.8 percent					

Table 4.—Analysis of variance of transformed data for living and cankered trees

	Group I		Group II		Group III	
Source of variation	df	ms	df	ms	df	ms
Replications	5	[2]1,032.15	5	[2]499.76	5	[1]544.40
Males	3	[2]4,860.73	3	212.57	3	460.94
Females	50	[2] 332.64	20	[2]454.35	16	194.20
Males X females	150	240.49	60	[1]213.13	48	180.74
Males - females X replications	909	206.06	390	142.06	299	234.49
R^2		.279		.311		.184

[1] Significant at 5 percent level of probability.
[2] Significant at 1 percent level of probability.
[3] There were 106 missing values for group I, 25 for group II, and 35 for group III.

DISCUSSION

The most significant finding presented in this paper is the survival of 58 cankered trees for nearly 30 years. Since nearly 90 percent of cankered seedlings die by the fourth year after inoculation, it seems remarkable that so many trees are alive after 30 years, and that the cankers are still active.

The high level of the survival trait in the control trees in the factorial test would normally indicate that this is not a resistance trait. However, the controls were selected in stands with high mortality (70 to 90 percent), and they were selected as controls for the immunity type resistance (Bingham and others 1960; Bingham and others 1969). Thus, I expected the survival trait to be as high or even higher in the controls, because the controls were cankered and the selected trees were not.

In most cases, the fungus was impeded from completely encircling the tree; but in three cases where the fungus completely girdled the bole, the trees were still alive and growing fairly well. So it is obvious that something about the physiology and genetics of these trees has enabled them to live considerably longer than expected (McDonald and others 1982, app. IV). I have observed four things that lead me to speculate on the general nature of the process: (1) abnormal cankers—the appearance of most of the cankers of older trees was not normal, for there were inactive-looking patches of sunken bark along the canker margins; (2) bark necrosis—cutting into these patches revealed dead tissue (brown and dry) beside living tissue, with a sharp boundary between, and microsections have so far revealed little mycelium in the living tissue directly adjacent to the dead tissue; (3) fungus inactivity—the fungus is quite active in some years, showing much normal-looking, yellow-orange coloration (fig. 1); however in most years, the fungus seems absent with no activity observed; (4) durable trees—trees appear to survive more girdling than normal.

Normally, western white pine can take a lot of damage to its vascular system—bears often will strip away one-half or more of the bark tissue without causing tree deaths. And the species is not particularly susceptible to heart rots or other organisms that can enter wounds. Nonetheless, those trees that still are alive with very large cankers that have girdled from 80 to 100 percent of the stem must have something special about their physiology that permits them to survive these high levels of damage.

This higher survival of cankered trees is fairly rare. Only 1.5 percent of the cankered trees in the older test were still alive and 12 percent in the more recent test. When averaged over all crossing groups, 25 percent of the variation could be explained by differences among families. This varied from 18 to 31 percent over the three groups. One of the main difficulties is that alive and cankered is the last of several resistance mechanisms that is expressed. So, by the time it can be observed, the total number of trees has been decreased by 40 to 50 percent. Future tests will concentrate on fewer families and more individual seedlings per family.

Being able to remain alive even though cankered is an important resistance mechanism for it permits the fungus to continue its life cycle, thus decreasing selection pressures for new races (Bingham and others 1971; Hoff 1982). This trait should be one of the priority mechanisms selected for in future varieties of blister rust resistant white pine. Van der Plank (1968) and Nelson (1978) argue for including this kind of resistance type (called horizontal resistance because it is nearly equally effective against all races of a disease organism) as a resistance base and then adding the immunity resistance types. The trees with horizontal resistance not only can survive, but the presence of horizontal resistance in the population suppresses the fungus population somewhat. This, in turn, causes the immunity genes to be less vulnerable.

Tree height and diameter data (table 2) illustrate that there is probably independence in the growth rate of trees with or without basal cankers. Further, because the height of the trees without basal cankers does not differ from Brickell's (1970) predicted height for trees of this age (age 27—39 ft [12 m], age 28—43 ft [13 m], age 29—43 ft [13 m] and age 30—46 ft [14 m]), comparison of the resistant trees and the original population does not show differences.

REFERENCES

Becker, W. A. A quantitative genetic analysis of blister rust resistance in western white pine. In: Genetics lectures, vol. 2. Corvallis, OR: Oregon State University Press; 1971: 91-99.

Becker, W. A.; Marsden, M. A. Estimation of heritability and selection gain for blister rust resistance in western white pine. In: Biology of rust resistance in forest trees. Misc. Publ. No. 1221. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972: 397-409.

Bingham, R. T. Artificial inoculation of large numbers of *Pinus monticola* seedlings with *Cronartium ribicola*. In: Biology of rust resistance in forest trees. Misc. Publ. No. 1221. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972: 357-372.

Bingham, R. T.; Squillace, A. W.; Wright, J. W. Breeding blister rust resistant western white pine. II. First results of progeny tests including preliminary estimates of heritability and rate of improvement. Silvae Genet. 9: 33-41; 1960.

Bingham, R. T.; Hoff. R. J.; McDonald, G. I. Disease resistance in forest trees. Annu. Rev. Phytopathol. 9: 433-452; 1971.

Bingham, R. T.; Olson, R. J.; Becker, W. A.; Marsden, M. A. Breeding blister rust resistant western white pine. V. Estimates of heritability, combining ability, and genetic advance based on tester matings. Silvae Genet. 18: 28-38; 1969.

Brickell, J. E. Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. Res. Pap. INT-75. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 22 p.

Comstock, R. E.; Robinson, H. F. Estimation of average dominance of genes. In: Gowen, J. W., ed. Heterosis. Ames, IA: Iowa State College Press; 1952: 494-516.

Hoff, R. J. Horizontal resistance. In: Proceedings of servicewide genetics workshop on breeding insect and disease resistant forest trees. Washington, DC: U.S. Department of Agriculture, Forest Service; 1982: 292-299.

Hoff, R. J.; McDonald, G. I. Improving rust-resistant strains of inland western white pine. Res. Pap. INT-245. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 13 p.

Hoff, R. J.; Bingham, R. T.; McDonald, G. I. Relative blister rust resistance of white pines. Eur. J. Plant Pathol. 10: 307-316; 1980.

McDonald, G. I.; Hoff, R. J.; Wykoff, W. R. Computer simulation of white pine blister rust epidemics. I. Mode formation. Res. Pap. INT-258. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 136 p.

Nelson, R. R. Genetics of horizontal resistance to plant diseases. Annu. Rev. Phytopathol. 16: 359-378; 1978.

SAS Institute, Inc. SAS user's guide: statistics. Cary, NC: SAS Institute, Inc.; 1982.

Steel, R. G. D.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Van der Plank, J. E. Disease resistance in plants. London and New York: Academic Press; 1968. 206 p.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U.S. GOVERNMENT PRINTING OFFICE: 1984—776-032/10,509 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-344

September 1984

Short Internodes in Western White Pine

R. J. Hoff
R. J. Steinhoff[1]

ABSTRACT

Irregularities in growth at the top of western white pine trees were related to three causes: (1) death of the terminal bud while dormant; (2) current-year terminal killed by insects, and (3) succulent terminal broken (usually by birds). In about half the cases, the broken succulent terminal also dies. In all irregularities related to causes 1 and 2, and those of cause 3 where the terminal died, lateral branches turned upward to replace the terminal, resulting in a moderate growth loss. On the broken succulent terminals that survived, one or more fascicular buds appeared. Evidence that such fascicular buds develop into new terminals was seen on growth from preceding years, and it is presumed that those on the current year's growth will also do so. In most cases, however, the internode will be very short for the year in which breakage occurs.

KEYWORDS: western white pine, short internodes, tree top damage, *Pinus monticola*

Western white pine (*Pinus monticola*) is easily identified from a distance because of its distinct and regularly spaced nodes (fig. 1A, B). The nodes are so distinct that measurements of several annual height increments can easily be taken at one time. In taking such measurements, we have frequently noticed that some internodes are much shorter than normal. These internodes are in a size range of several inches (fig. 2A, B, C) as opposed to normal ones of 2 to 3 feet (0.6 to 0.9 m). We have asked several silviculturists, researchers, and forest managers who have had much experience with white pine about the cause of the short internodes, but none could satisfactorily explain the phenomenon. The most frequent explanation offered was that, as a result of death or breaking of the terminal, a lateral branch became dominant.

However, that did not explain what we were seeing. When the terminal dies and one or more laterals become dominant or codominant, the broken dead stub often was still visible. The node was decidedly asymmetrical if a single lateral branch became dominant (fig. 3), or multiple tops resulted if two or more branches became codominant (fig.4). The growth for the year, although reduced, was usually 50 percent or more of normal. In contrast, the length of the short internodes is often less than 25 percent of that of preceding or succeeding "normal" internodes and the branching pattern at the nodes often appears to be nearly normal.

We observed three factors that resulted in irregular height growth of white pines. One was a dead terminal bud (fig. 5). For some reason, most likely insect attack, the bud dies before spring bud break. The second type of damage was caused by an insect attack that killed the terminal during the summer (fig.6). The third kind of damage is a result of terminals broken during the summer (fig.7). The broken and dead stubs often remain visible for several years (fig. 4, 5). As the tree continues to grow, the irregularity is overgrown and only an asymmetrical area remains visible.

We have seen another type of growth irregularity in grand fir (*Abies grandis*) that could also give rise to short internodes but have not observed it in white pine. In grand fir, some terminal buds that appear dead at the normal time for spring bud break are either in an extended dormant state, or are mostly dead but contain some living meristematic tissue that can form a new bud, for they produce a short internode later in the summer. If that shoot can later gain dominance over lateral branches, the result would be a short internode similar to those observed in white pine.

Although we did not actually see the cause of summer terminal breaks in plantations where we made measurements, we have seen what we think is the cause in other plantations. Robins, crows, ravens, bluebirds, even hawks and eagles, have been observed sitting on the terminals of trees. The bigger birds bend the terminals horizontally. The smaller birds (for example, bluebirds and pine siskins) do not seem to be heavy enough to cause such bending. We have seen them land on white

---

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

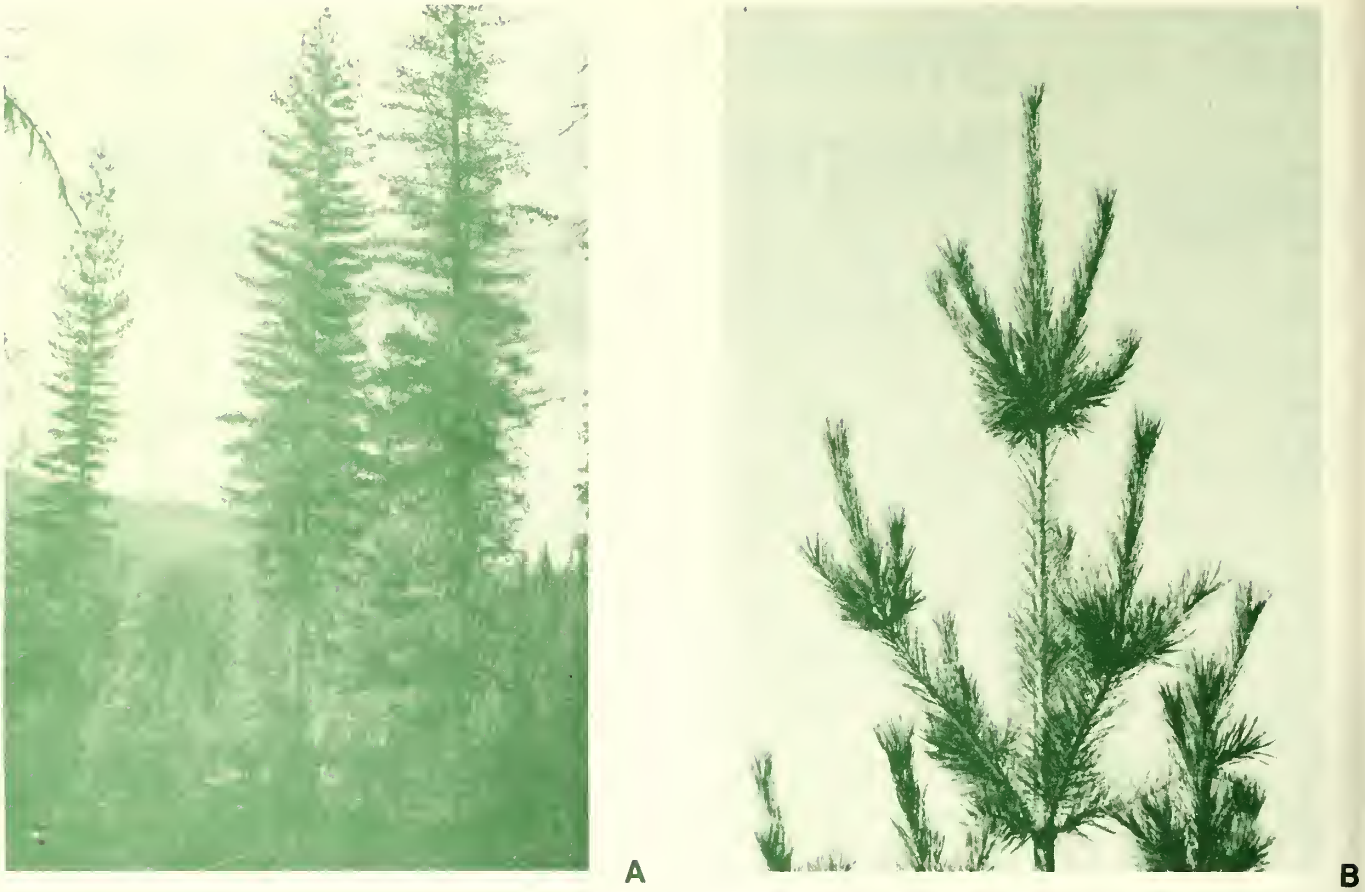


Figure 1.—Western white pine showing regular nodes and internodes: A, naturally regenerated white pine about 60 years old; B, planted white pine, 28 years old.

pine, lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*) without causing damage. But we have seen birds the size of robins break succulent terminals.

During the summer of 1983, we measured several years' growth on western white pines in three separate plantations. One of the plantations had a high frequency of irregular tops, and the trees were short enough so we could measure each internode with a meter stick, starting at the top using a 16-ft (4.8-m) orchard ladder; thus, the terminal was at eye level when measured. We were also counting a sample of needles on the terminal so we had to be close enough to handle it.

After we had taken data on several hundred trees, the likely cause of the short internodes became obvious (fig. 8, 9). The short internode usually occurs when the terminal is broken, some of the fascicle buds develop, and one becomes the new terminal. Occasionally the terminal is broken when it has nearly completed elongation and consequently looks normal from the ground (fig. 10). However, a closer look reveals that the termina has been broken and that many fascicle buds have appeared (fig. 11).

Figure 12 shows a situation where a terminal was broken in 1981 and two buds developed that have bee maintaining equal dominance. An irregularity of this type may explain the occasional tree seen in the forest with two nearly identical stems above a certain level. Notice, too, that the 1981 stub (internode) is much shorter than the 1981 growth of any of the laterals. In addition, the node (top of the 1981 break) has no lateral This lack of lateral branches could easily lead to confusion if one were attempting to measure annual grow increments at some later date, especially if only one bud had developed. The minor irregularity would soo be overgrown and the combination of 1981 stub and 1982 growth would appear to be a single internode rather than two.

Figure 2.—Short internodes in western white pine: A, on an older tree, about 7 inches (17 cm); B, on a younger tree, about 6 inches (15 cm); C, on a younger tree, about 3 nches (7 cm).

Figure 3.—Western white pine with a broken top. Old dead stub is still present. Two lateral branches competed for dominance, but one has outgrown the other.

Figure 4.—The top of this tree was broken during the summer of 1982. Three lateral branches turned up; one usually becomes dominant.

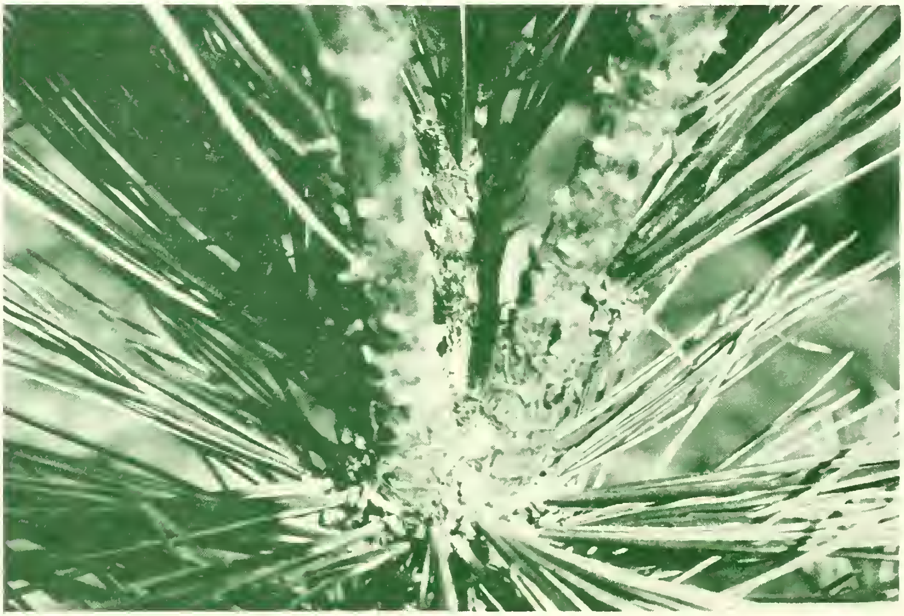


Figure 5.—The dormant terminal bud of this tree died some time before spring.

Figure 6.—The terminal of this tree was killed by insect attack after growing several inches.

Figure 7.—The top of this tree was broken during the summer of growth, and the stub of the terminal has died.

Figure 8.—The top of this tree was broken during the summer of growth. Three fascicle buds have developed to replace the old terminal. If one can gain dominance over the lateral branches, a short internode will result.

Figure 9.—The top of this tree was broken during the summer of growth. Several fascicle buds have developed.

Figure 10.—The top in this tree appears normal; actually it is broken. See figure 11.

Figure 11.—Top of tree shown in figure 10. The top was broken during the summer. Most of the needles have been stripped away to reveal the buds.

Figure 12.—A, the top of this tree was broken in 1981. Two fascicle buds developed and the new tops have maintained equal dominance; B, closeup of A.

Table 1.—Top damage and frequency of buds on broken terminals in three western white pine plantations

		Top damage (observed 1983)			
Plantation	Total trees	Dead terminal bud (winter)	Insect killed terminal bud	Broken terminal	Broken terminals with new buds
VQ plot	287	2	12	3	0
Canyon Creek	562	4	1	63	31
Ida Creek	250	4	2	3	1

Frequency of terminal damage and frequency of broken terminals with fascicle buds at the three plantations are tabulated in table 1. After viewing the buds at Canyon Creek, we used binoculars to look at the treetops at the VQ and Ida Creek plots.

The percentage of trees with at least one growth irregularity in the last 6 years was 12 at Ida Creek, 19 at the VQ plot, and 34 at Canyon Creek. These percentages do not include trees with short internodes, unless we could verify that they resulted from terminal breakage and subsequent fascicular bud development.

The point that we want to emphasize is that short internodes often result from summer breakage followed by development of fascicle buds. The reduction in height growth that results is greater than if the broken top had just died and been replaced by a branch. So, in any analyses of height, this and other irregularities must be recognized and an attempt made to compensate for the growth reductions.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U.S. GOVERNMENT PRINTING OFFICE: 1984—776-032/10,508 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-345

October 1984

Characteristics of Fireline Blasted With Linear Explosives: Initial Test Results

Richard J. Barney[1]

ABSTRACT

Based on limited data, water-gel provided a slightly wider and deeper fireline with more feathering of ejected material than did Ensign-Bickford cord. Soil moisture conditions, closeness of blasting material to the ground, and other factors may explain these differences.

KEYWORDS: fireline, blasting, linear explosives, water-gel, fireline cord, fireline construction

Fireline performance and construction are continually of interest to personnel engaged in wildfire suppression and fire use. Throughout the years, numerous techniques for fireline construction have been tested, evaluated, and used. Some provided real improvements in wildfire suppression; others were merely tried and rejected for failure to meet an array of evaluation criteria. Today, with increased costs for equipment and labor, and fewer fire suppression personnel available for duty, alternative methods of fireline construction are in demand. Fireline requirements for prescribed burns add a whole new array of needs and associated problems.

Explosives have for many years been considered a possible tool for wildfire fireline construction. In 1947 Johnson described use of Army explosives as a potential aid to fire suppression personnel. Ten years later, Banks and Fenton (1957) discussed use of Primacord[2] for blasting fireline. Since those early works, which indicated possibilities for operational use, fireline construction with explosives has been an on-again, off-again proposition. Explosives in linear form were found to produce fireline which was as good as, and sometimes superior to, fireline constructed using more traditional methods. In the mid-1970's the USDA Forest Service Equipment Development Center in Missoula, MT (MEDC) reviewed fireline explosives, developed nonincendiary explosive cord, and evaluated applications. Lott (1977, revised) discussed at length fireline explosive use and procurement instructions. Subsequently, another type of explosive, water-gel, also in a linear configuration, was evaluated and described by Ramberg (1978).

Since that time scattered work has been done in fireline explosive evaluation and development. Although one type of linear explosive has been approved for building wildfire fireline, its use has been limited in many areas. This explosive is the seven-strand Ensign-Bickford fireline cord. With an increase in the number of personnel trained to use explosives, fireline construction with explosives is becoming more widespread.

Unfortunately, explosives are being used without benefit of adequate guidelines or cost figures to help managers make sound decisions and allocations. The need for more detailed information and further evaluation of explosive techniques is evident. Such determinations have been made in the past, but the information was either local in nature or limited in depth, and not widely available to other users.

The British Columbia Forest Service (1972) provided quantitative measures of fireline constructed with linear explosives. These tests showed fireline could be blasted up to 16-inch widths, depending upon type of explosive and method of deployment. Little published information describes the quality of finished fireline constructed with linear explosives. To compare fireline built with explosives to that built by other construction methods, such as hand crews or bulldozers, it is necessary to have common measurements and criteria with which to make sound cost comparisons. This information is necessary not only for an evaluation of economic considerations of fireline construction using different methods,

---

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

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

but also to provide the basis by which simulations could be made using several methods for various forms and levels of planning. Therefore, a study was begun to determine physical characteristics of fireline constructed with linear explosives. Initial results are given here.

METHODS

Sites were chosen west of Missoula on the Nine Mile Ranger District of the Lolo National Forest and in the University of Montana's, Lubrecht Experimental Forest, about 25 miles (40 km) east of Missoula. The sites included representative ground fuels and cover types important in western Montana. The sites were predominantly Douglas-fir on a southerly exposure, lodgepole pine, and clearcut units. We selected three general classes of ground cover as providing a range of conditions for our initial evaluation process—open grass, moderate fuels of down and woody materials in addition to some brush, and a heavy fuel situation where considerable down and dead material was present along with heavy brush.

Figures 1, 2, and 3 show examples of the cover types where blasting tests were carried out. Figure 1 represents fuel model 10, figure 2 represents fuel model 8, and figure 3 represents fuel model 2 (Anderson 1982). At each site, certain preblast material was inventoried. Permanent stakes were placed in the ground to reestablish the same sample points following blasts so that material removed from the area could be accurately measured.

Most available linear explosives come in 100-foot (30.5-m) lengths; therefore, one 100-foot transect was laid out at each test site with twenty sampling points at 5-foot (1.5-m) intervals along each transect. The transects were oriented to cover representative parts of each site. Data were recorded at each of the points both before and after blasting. The measurements of primary interest were width of fireline mineral soil after blasting, average depth of the fireline, and average width of ejected material on either side of the fireline (fig. 4).

Figure 1.—Heavy cover type (fuel model 10).

Data also were recorded for vegetation removed, type of ground, and size of material encountered. These factors were considered important by Ramberg (1978) and Lott (1977). The two explosives used in this study were Ensign-Bickford fireline explosive cord (7 strand) and IRECO's "Iremite 60" water-gel. These will be referred to throughout the paper as Ensign-Bickford cord and water-gel.

Figure 2.—Medium cover type (fuel model 8).

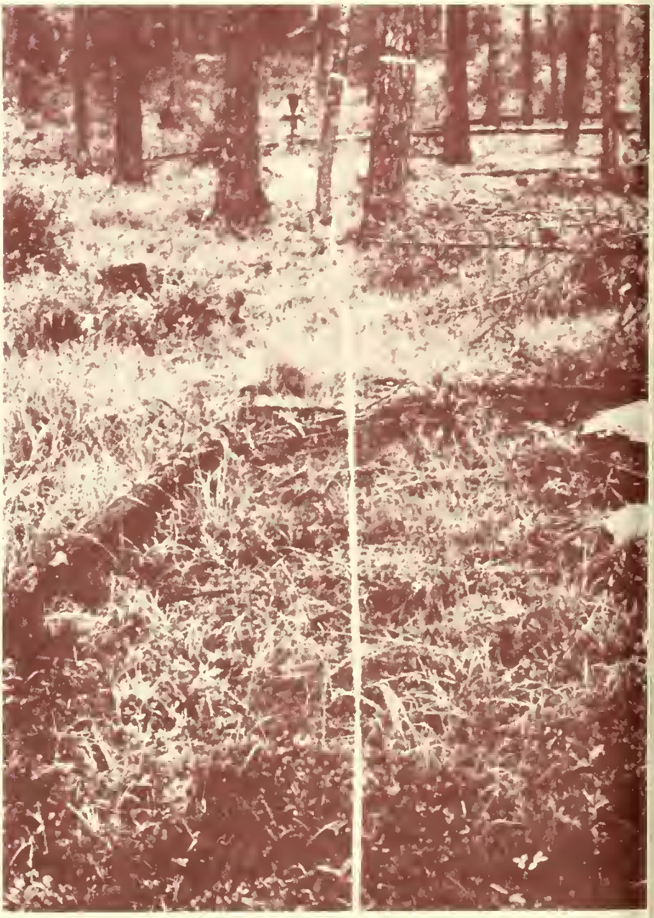


Figure 3.—Light cover type (fuel model 2).

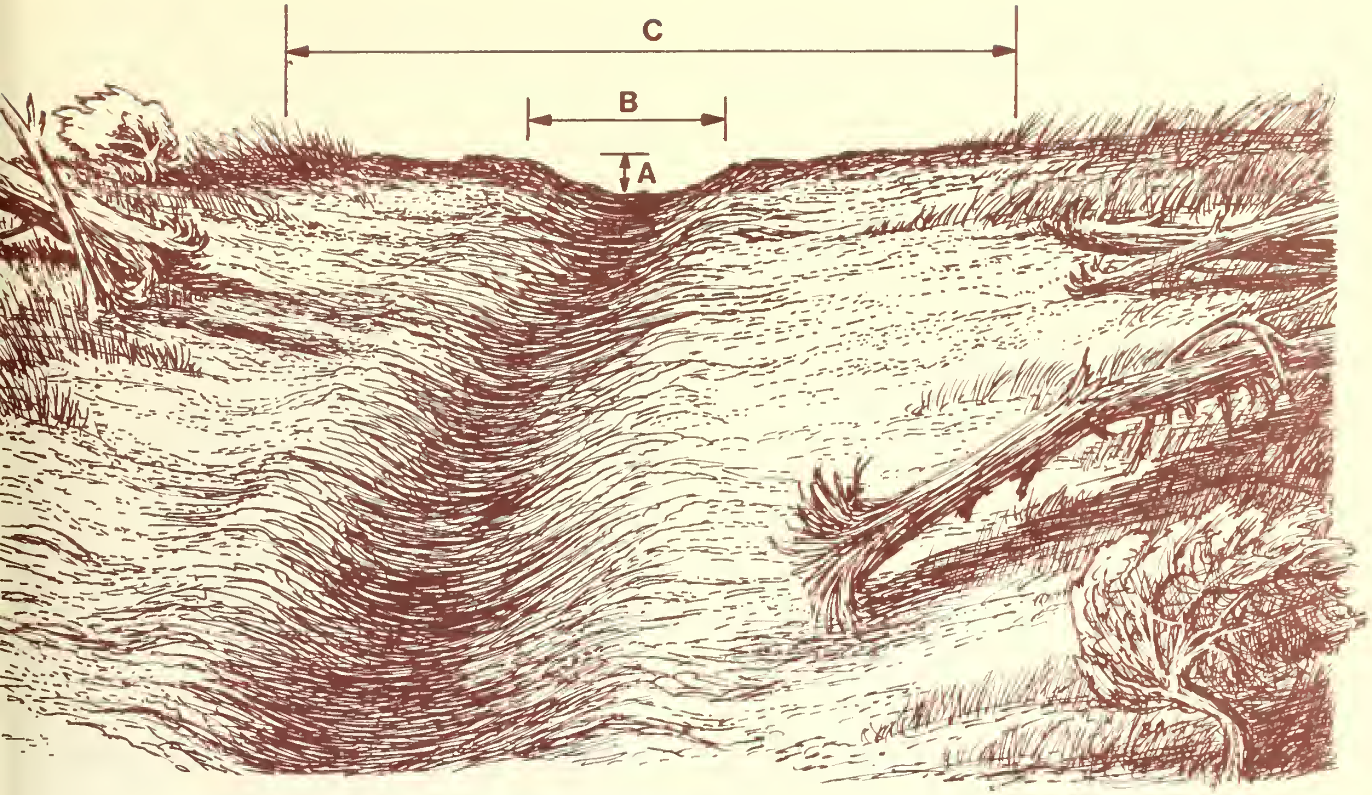


*Figure 4.—Measurements of primary interest in the linear explosives study: **A**, fireline depth; **B**, fireline width; **C**, width of ejected material.*

Table 1.—Number, means, and standard deviations for measurements taken of fireline blaster with two types of linear explosive in four fuel types

		Ensign-Bickford					
		Width		Depth		Feather	
Fuel	N	X̄	SD	X̄	SD	X̄	SD
		Inches				Feet	
Light	36	17.22	5.70	2.36	0.76	8.04	2.92
Medium	36	11.25	9.39	1.56	1.42	10.79	5.89
Heavy	[1]36	13.33	5.66	3.61	1.46	8.67	2.25
Combined	[2]108	14.06	8.85	2.51	1.51	9.17	4.15

		Water-gel					
		Width		Depth		Feather	
Fuel	N	X̄	SD	X̄	SD	X̄	SD
		Inches				Feet	
Light	126	16.10	5.87	2.40	1.32	10.57	2.95
Medium	90	17.19	6.30	2.61	1.10	10.57	4.22
Heavy	54	17.11	4.72	3.5	1.00	12.24	3.59
Combined	270	16.67	5.81	2.69	1.26	10.88	3.63

N = number of observations
X̄ = mean value
SD = standard deviation

[1] N = 18 for Ensign-Bickford width only.
[2] N = 90 for Ensign-Bickford width only.

Normal operating procedures and safety practices detailed in the Blaster's Handbook (USDA 1980) were observed in all blasting operations. The tests were made by smokejumpers from the Missoula Aerial Fire Depot and Montana State Forestry personnel in conjunction with blasting training exercises. At least three blasts of each type of explosive were made on each approved date. Appendix I is the field data collection form; appendix II is the instructions issued for completing the form.

ANALYSIS

Data from field forms (appendix I) were entered into the computer at the Northern Forest Fire Laboratory for analysis.

Table 1 shows means and standard deviations for the basic measurements taken. The average width of the fireline in each cover type, the average depth blasted into the mineral soil, and the average width of the ejected material or feathering (dusting effect) are indicated. Many people who have used fireline cord, especially in prescribed burning activities, believe that ejected soil (the feathering effect) created by blasting adds an additional 6 to 12 feet (1.8 to 3.7 m) or more of effective fireline if the line is blasted shortly before ignition. The ejected moist soil has a retarding effect on the combustion process slowing down the rate of spread and diminishing fire intensity. Ejected material also has a retarding effect when the soil is drier or after some time; however, it is most effective immediately after blast when the soil is usually dampest. Dust coatings on fuels adjacent to forest roads and trails are commonly known to slow or stop fires.

We also noted that in many cases some minor fireline cleanup work had to be done to at least break the bridging of downed logs or limbwood that was not blasted away. Some advocates of fireline blasting indicate that sawing before blasting is most appropriate and less hard on saw chains; however, much material is often blasted out of the way and a crew need only saw what remains after the explosion.

DISCUSSION AND CONCLUSIONS

There is no question that the 100-foot (30.5-m) segments of blasted line, after cleanup, should be effective firebreaks. Figures 5 and 6 show before and after views of a blasted line in fuel model 2. The utility of blasting must next be coupled with the cost of the material used and the total cost of putting it on the ground and blasting. This then can be compared with production rates of crews or bulldozers in similar situations to determine which is the most cost-effective technique.

Data in table 1 suggest a slight statistical difference in performance characteristics between the two types of linear explosives used in our test. Line width blasted to mineral soil was on the average slightly greater using water-gel than the Ensign-Bickford cord. It is difficult to determine specifically why this occurred; however, one factor seems to be that the water-gel will lie closer to the ground. The material is much more pliable than the Ensign-Bickford cord and conforms to the irregularities of the ground more easily. Water-gel has more total explosive per unit length; however, Ensign-Bickford cord has more retardant to prevent fires from being ignited. Soil moisture content may also have played an important role, but we did not find any significant relationships between soil moisture and line width. This was evaluated for both explosive types and each fuel type as well as with all data combined. Trends are

Figure 5.—Light cover type (fuel model 2) before blasting.

Figure 6.—Light cover type (fuel model 2) after blasting.

indicated, but they are not supported well enough by our limited data base to provide definitive answers.

Line depth created by either explosive was similar, regardless of fuel. No strong relationships were found between soil moisture and line depth. However, data did lend some support to the assumption that increased soil moisture would produce deeper line. The British Columbia studies produced this type of result. Additional samples could improve our information base and possibly indicate stronger relationships between depth of blasted line and soil moisture content.

Although line width varied, the average width of feathering for both types of explosives was similar. Regression analysis of soil moisture and width of ejected material showed weak relationships. Some plotted data showed a relationship; however, the limited amount and range of data preclude any definitive conclusions.

Any brush that was over or near the blast area was totally removed or the leaves were stripped from the branches. In several relatively thick alder patches branches were stripped clean of leaves and branches within about a foot of the cord were blown away. Many of the roots were also severed.

Rotten material, including logs and stumps, was especially susceptible to removal by blasting. The blast blows away much of this material or breaks it up so completely that it can be kicked aside or completely removed with minor shovel work.

Sound logs about 4 inches (10 cm) or less in diameter usually were broken by the blast unless the log had been positioned a foot or more above the cord before blasting. Materials larger than 4 to 6 inches (10 to 15 cm) in diameter were very seldom blasted apart or removed unless they had been positioned directly on top of the cord. If the cord was placed on top of a larger log, the log was almost never blasted totally apart. However, larger logs could be blown apart if they were wrapped with explosive. Considerable material was eroded from large logs that were not broken; the amount depended on log soundness and whether they were located above or below the explosive. If we wrapped the log with the main line or a short strip of explosive, it could usually be easily severed.

Contrary to some opinions, neither type of explosive would blow a clean line if it was merely laid along the ground and placed over or under logs. Some material had to be removed after the blast. However, only minimal effort was needed to clean up the line. It was the consensus of those involved with each blast that line cleanup would require little additional effort by one or wo persons.

A three- to six-person crew can build a lot of fireline n a day with explosives, far in excess of what a 20-person crew could produce with handtools. Therefore, here are applications in wildfire control and prescribed fire that must be considered where labor is not available or where time is severely limited.

FUTURE RESEARCH

Our results indicate some initial responses in some cover types to fireline blasting. We are in the process of making tests in several other cover types. When this phase is done, we will have extensive data on characteristics of line built in various cover types and should be able to define any areas where blasting is not productive. We then plan to develop cost-per-unit data for blasting in field operations.

Some of our observations made on fireline blasting were parallel to those made by MEDC personnel in earlier reports. One that we believe has much promise is that fireline created by linear explosives has a tendency to revegetate at a much more rapid rate than does fireline built conventionally with handtools. This will be reported on following another field season. If, indeed, subsequent study supports our initial observations, environmental quality considerations may be a major factor in offsetting the cost of explosives.

Blasting fireline has a place in the continually improving fireline construction tool box. Specific data on general costs, cost per unit, environmental considerations, benefits, and other factors are needed to determine the true utility of this method. Changing budgets, management requirements, and manpower availability all have a role in determining the amount and extent of use of fireline blasting, in both fire suppression and prescribed burning. Knowing the physical characteristics of blasted line is an important piece of a large picture. Such information will support the more appropriate application of this emerging technology.

REFERENCES

Anderson, Hal E. Aids to determining fuel models for estimating fire behavior. General Technical Report INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 22 p.

Banks, W. G.; Fenton, R. H. Primacord tested for blasting fireline. Fire Control Notes. Washington, DC: U.S. Department of Agriculture, Forest Service; 1957; 18(4): 164-167.

British Columbia Forest Service. Fireline construction using explosives. Progress Report-Project No. 125. Victoria, BC: British Columbia Forest Service, Protection Division, Planning and Research Section; 1972. 20 p.

Johnson, G. B. Army explosives for hazard reduction. Fire Control Notes. Washington, DC: U.S. Department of Agriculture, Forest Service; 1947; 8(1): 42-44.

Lott, J. R. Fireline explosives: use and purchasing instructions. ED&T 2004, Explosives for Fireline Construction (rev.). Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1977. 16 p.

Ramberg, R. G. Water gel explosives for building fireline—project record. ED&T 2697, Blasting Prescribed Fire Control Lines. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1978. 20 p.

U.S. Department of Agriculture, Forest Service. Blaster's Handbook, FSH 7109.51. Washington, DC: U.S. Department of Agriculture, Forest Service; 1980. 146 p.

APPENDIX I
FIRELINE EXPLOSIVE STUDY

Field Data Collection Form

I. Explosive type
Ensign-Bickford or water-gel ________
II. Identification
1. Date __________ __ __ __ __ __ __
2. Time hours _______ __ __ __ __
3. USFS Region _____
4. Forest ________________
5. Ranger District ________________
6. Scheduled test no. ________ __ __
7. Wildfire name ________________
8. Prescription fire name ________________
9. Observer ________________

III. Environmental conditions
1. Air temperature ______ __ __ __
2. Relative humidity ______ __ __
3. Percent slope ______ __ __
4. Aspect ________ __ __
5. Soil type __________ __
6. Soil moisture __ __

IV. Fuel information
1. Fuel type and cover ____________________ __
2. Fuel model __________ __ __

V. Preblast data
1. Location of measurement ________________ __ __
2. Litter layer __________ __ __ __
3. Duff layer __________ __ __ __
4. Grass height ________ __ __ __
5. Grass - percent ground coverage ______ __ __ __
6. Brush cover - percent ______ __ __
7. Number of brush intercepts: 0-¼ ________ __ __
(by size class) ¼-½ ________ __ __
½+ ________ __ __
8. Brush foliage condition __________ __
9. No. of log intercepts: 3"-6" ________ __ __
6"-12" ________ __ __
12"+ ________ __ __

VI. Postblast data
1. Location of measurement ________________ __ __
2. Width of blasted line to mineral soil ________ __ __
3. Width of ejected material ________ __ __ __
4. Depth of blasted line ________ __ __
5. No. of root intercepts: 0-¼ ______ __ __
(by size class) ¼-½ ______ __ __
½+ ______ __ __
6. No. of brush intercepts: 0-¼ ______ __ __
(by size class) ¼-½ ______ __ __
½+ ______ __ __
7. Percent brush defoliation ______ __ __
8. Number of log intercepts: 3"-6" ______ __ __ __
6"-12" ______ __ __ __
12"+ ______ __ __ __

VII. Remarks:

APPENDIX II
INSTRUCTIONS FOR PREPARATION AND CODING OF FIRELINE EXPLOSIVES STUDY

Field Data Collection Form

General. One form will be prepared for each observation made. All applicable blanks will be filled in on the left-hand side of the form at the time of each observation. A new form will be used at each designated measurement point in the explosive line in scheduled tests. Observations and measurements on wildfires and prescription fires will be made to the extent time and fire conditions permit. Coding of forms may be completed later.

I. Explosive type. Check correct blank and code 1 for Ensign-Bickford and 2 for water-gel.

II. Identification

1. Date. The date will be entered and coded; August 8, 1982, would be 080882.
2. Time. Use a 24-hour clock. 2:30 p.m. is 1430. When coding, enter only to the nearest hour; i.e., 1335 would be 1400; 1325 would be 1300.
3. USFS Region. Enter number of Region—1, 4, 6, etc.
4. Forest. Enter name of Forest.
5. Ranger District. Enter name of District.
6. Scheduled test number. Enter number of test. Code direct—1 = 01; 11 = 11; etc.
7. Wildfire name. Enter fire name.
8. Prescription fire name. Enter prescription fire name or other identifying term.
9. Observer. Enter observer's name.

III. Environmental conditions

1. Air temperature. Enter as degrees Fahrenheit. Code direct—45 = 45, etc.
2. Relative humidity. Enter as percent. Code direct—25% = 25, etc.
3. Percent slope. Enter the percent slope in the direction of line construction. Code 5% as 05; 99% and above are coded 99.
4. Aspect. Enter as direction; i.e., north, northwest, south, etc. for eight compass points. Code north as 01 and proceed clockwise on compass to northwest as 08.
5. Soil type. Enter and code as follows:

Sandy	1
Clay	2
Loam	3
Gravel	4
Light rocky (occasional rocks)	5
Medium rocky (10-50% rocks)	6
Heavy rocky (51-75% rocks)	7
Rocky (75%+ rocks)	8
Peat or heavy organic	9

6. Soil moisture. Enter as percent. Code direct—5% = 05; 15% = 15, etc. Soil moisture will be determined in the lab.

IV. Fuel information

1. Fuel type and cover. Record and code as follows:

Light - grass with forbs	1
Medium - open pine stands	2
Medium-heavy - brush predominating	3
Heavy - dense conifer stand	4
Extreme - clearcut slash	5

2. Fuel model. Enter the NFDRS fuel model appropriate for the area; i.e., model A = 1; model E = 5, etc.

V. Preblast data

1. Location of measurement. Enter as feet from ignition end of explosive line. Code direct—5 feet = 05, etc.
2. Litter layer. Enter as depth in inches to nearest ¼ inch. Code direct—2 inches = 200; 4¾ inches = 474, etc.
3. Duff layer. Enter as depth in inches to nearest ¼ inch. Code direct—2 inches = 200; 4¾ inches = 475, etc.

(con.)

4. Grass height. Enter in inches to nearest ½ inch. Code direct—2 inches = 020; 3½ inches = 035, etc.
5. Grass—percent ground cover. Enter as visual estimate to nearest 10%. Code direct—10% = 10, etc.
6. Brush cover percent. Visual estimate to nearest 10%. Code direct—10% = 10, etc.
7. Number of brush intercepts. Enter as total number by size class. Code direct—11 intercepts = 11, etc.
8. Brush foliage condition. Enter and code as follows:

Green	1
Cured	2
Shed	3

9. Number of log intercepts. Enter and code as follows (number of log intercepts measured from last point to current measurement point): 01 = 1 intercept; 05 = 5 intercepts, etc.

VI. Postblast data

1. Location of measurement. Enter as feet from ignition end of line. Code direct—5 feet = 05; 15 feet = 15, etc.
2. Width of blasted line to mineral soil. Enter as inches to nearest inch. Code direct—3 inches = 03, etc.
3. Width of ejected material. Enter to nearest foot. Code direct—1 feet = 015; 15 feet = 150, etc.
4. Depth of blasted line. Enter to nearest inch. Code direct—1 inch = 01, etc.
5. Number of root intercepts. Enter as total number by size class. Code direct—10 intercepts = 10, etc.
6. Number of brush intercepts. Enter total number of intercepts by size class. Code direct—5 intercepts = 05; 11 = 11, etc.
7. Brush defoliation. Enter ocular estimate to nearest 10%. Code direct—10% = 10, etc.
8. Number of log intercepts. Enter and code as follows: 01 = 1 intercept; 05 = 5 intercepts, etc.

VII. Remarks. Enter any pertinent information not specifically called for in instructions—such items as incomplete detonation of explosives, aborted test, etc.

U.S. GOVERNMENT PRINTING OFFICE: 1984—776-032/10514 REGION NO.

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-346

December 1984

Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

Carolyn H. Chase

Spotting Distance from Wind-Driven Surface Fires — Extensions of Equations for Pocket Calculators

Carolyn H. Chase[1]

ABSTRACT

Extends equations for calculating the maximum spot fire distance to include wind-driven fires burning in surface fuels as a firebrand source. Predictions are based upon prevailing windspeed, vegetational cover, and local terrain. The equations can be used on a programmable pocket calculator. Previous methods of calculating spotting distance from torching trees and burning piles are also included. For copies of a program for the Texas Instruments TI-59, send eight blank TI-59 magnetic cards to the author. (Only two cards are required if the user has the previous version of the program.) Potential uses are in fire management planning and in predicting real-time fire behavior.

KEYWORDS: spot fire, spotting, firebrands, fire management

MODEL DESCRIPTION

Spot fires ignited by flying embers from wildfires and prescribed fires have long been a problem for fire managers. Spotting is difficult to prevent; therefore it is useful to be able to forecast when spotting is likely to occur and predict its maximum distance and direction.

Roussopoulos and Johnson (1975) and Rothermel (1983) provide guidelines based on fireline intensity that indicate when severe fire behavior such as torching, crown fires, and spot fires can be expected. Albini (1979, 1981) and Chase (1981) document calculation of the maximum distance firebrands can travel when the source of the firebrands is:

1. The transient flame produced by a torching tree (or group of trees burning with a single flame structure), and
2. A continuous steady flame as provided by burning piles of slash or "jackpots" of heavy fuel.

---

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

Albini (1983) considers another source of firebrands:

3. A wind-driven fire burning in surface fuels (such as grass, shrubs, litter) without timber cover.

This note extends the equations for predicting maximum spotting distance to include the third case, and documents a revised program for the Texas Instruments TI-59[2] calculator that includes all three sources.

In all three instances an updraft lofts burning material vertically; then it is carried horizontally by the wind while also falling back to earth to land some distance downwind from the source. In the case of wind-driven fires burning in surface fuels, the firebrand drifts downwind as it is being lofted. When firebrands are produced by surface fires, significant overstory or timber cover may provide a barrier for the firebrands and interfere with the development of an updraft that lofts the firebrands vertically. Consequently, spotting distance in these situations is generally insignificant.

Albini's model covers intermediate range spotting (generally a few tenths of a mile to a mile). It does not address short-range spotting of a few tens of yards from fires of low intensity or very long-range spotting associated with severe fire behavior such as crown fires and firewhirls. The firebrand of interest is the one of optimum size. That is the particle whose dimensions, weight, and aerodynamics allow the wind to loft it a considerable distance and that is still burning when it lands. Particles smaller than optimum could travel farther, but would burn up before landing. Particles larger than optimum would often be burning when they land, but would not travel as far. The model does not consider the numbers of optimum firebrands produced by a fire. If particles of optimum size are not present, spot fire distance will be less than the maximum predicted. The model does not address whether the firebrand causes an ignition, or the number of spot fires caused.

Mountainous terrain is modeled as a washboard. If this simple representation does not describe your situation, perhaps the model will not give you a good approximation of spotting distance.

The surface-fire spotting model requires two fuel-model-dependent parameters used to relate thermal energy to windspeed. Albini (1983) derives these parameters for 12 of the 13 standard NFFL fuel models (Albini 1976; Anderson 1982) and they are presented in table1 as parameters A and B. A is used as a coefficient in the windspeed function and B is used as a power. Some models ordinarily have overstories, but are sometimes used to represent fuels without overstory cover. Model 9 (hardwood litter) can be used when the deciduous overstory is bare of leaves or the stand is sparse. Model 10 (timber litter and understory) is sometimes used to represent timber harvest debris overgrown with shrubs or other vegetation. Model 8 (closed timber litter) was omitted in Albini's analysis because it is seldom used to represent a model without cover.

The model-dependent parameters can also be derived for custom fuel models (Burgan and Rothermel 1984). Calculation speed and memory considerations preclude calculation of these parameters in the TI-59 program. Current plans are to include derivation of surface-spotting parameters for custom fuel models in the expected update of the BEHAVE system of interactive computer programs (Andrews 1983; Andrews, review draft; Burgan and Rothermel 1984).

---

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

Table 1.—Corrected values of windspeed function parameters for 12 of the 13 NFFL fuel models (erratum notice, Albini 1983). Units of A are seconds; B is dimensionless.

Fuel model	Coefficient A	Power B
	Seconds	
Grass and litter		
1 Short grass	545	−1.21
2 Grassy understory	709	−1.32
3 Tall grass	429	−1.19
9 Hardwood litter	1121	−1.51
Shrub types		
4 Mature chaparral	301	−1.05
5 Young chaparral	235	− .92
6 Dormant brush	242	− .94
7 Southern rough	199	− .83
Logging slash		
10 Overgrown slash	224	− .89
11 Light conifer slash	179	− .81
12 Medium conifer slash	163	− .78
13 Heavy conifer slash	170	− .79

When available, these parameters can be entered in the TI-59 program according to the operating procedures described subsequently.

Users who desire to use NFFL model 8 (closed timber litter) as a surrogate for fuels without overstory should create a custom model with the BEHAVE system using parameters for model 8. The updated version of BEHAVE will then calculate the surface spotting parameters required.

The predictions provided by the program are only as good as the model on which they are based. Confidence in predictions can be improved by field verification. Personal communication (Catchpole 1983) indicates that the model may underpredict maximum spotting distance in eucalyptus forests due to the aerodynamical nature of the tree bark. The author invites submission of any validation data obtained.

Equations are given for English and metric units of measure. The TI-59 program uses English units, so only English units appear in the text. The transformation of the 20-foot reference windspeed to windspeed at heights required for input to Albini's (1983) model has been incorporated in the equations. The logarithmic windspeed profile and the power law profile both yield similar results when referenced near the surface and projected upwards; therefore the power law profile was used because it is simpler.

Table 3 of Albini (1983) presents values necessary for the derivation of the spotting parameters. The table was later found to contain inaccuracies. Corrected table entries are presented in the Appendix (table A). Also presented in the Appendix are the corrected values for the numerical examples appearing in Albini (1983).

SUMMARY OF EQUATIONS

Symbol	English units	Metric units	Description
Torching tree option			
d	inches	cm	Diameter at breast height (d.b.h.) of tree(s) torching out
h	ft	m	Height of burning tree(s)
n	none	none	Number of trees burning simultaneously to produce a single merged flame and buoyant plume structure
h_F	ft	m	Adjusted steady flame height (perpendicular measurement from base of flame to tip of flame)
d_F	none	none	Adjusted steady flame duration
Pile burning option			
H_F	ft	m	Continuous flame height for pile burning
Wind-driven surface fire option			
A	s	s	Fuel model-dependent parameter used as coefficient in windspeed function (see table 1)
B	none	none	Fuel model-dependent parameter used as power in windspeed function (see table 1)
f(U)	s	s	Windspeed function
E	Btu/ft	kJ/m	Strength of a thermal updraft generated by a wind-driven line fire
I	Btu/ft/s	kW/m	Fireline intensity
Common to all options			
$\bar{h}$	ft	n	Mean vegetation cover height downwind of source (see "Operating instructions")
$\bar{h}_c$	ft	m	Minimum value of $\bar{h}$ used to calculate spotting distance using the logarithmic windspeed variation with height (Albini 1981)
$\bar{h}^*$	ft	m	The greater of $\bar{h}$ and $\bar{h}_c$
U	mi/h	km/h	Windspeed 20 feet (6 m) above vegetation
D	mi	km	Ridge-to-valley horizontal distance (map)
H	1000's of ft	mult. of 300 m	Ridge-to-valley elevational difference
M	none	none	Code number for location of firebrand source 0 = midslope, windward side 1 = valley bottom 2 = midslope, leeward side 3 = ridgetop
z(0)	ft	m	Initial firebrand height above ground
F	mi	km	Flat-terrain spotting distance
S	mi	km	Mountainous-terrain spotting distance (map)

uations Using English Units

$$= \begin{cases} \left. \begin{array}{ll} 4.24d_F^{0.332}(h_F) + h/2, & h/h_F \geq 1 \\ 3.64d_F^{0.391}(h_F) + h/2, & 0.5 \leq h/h_F < 1 \\ 2.78d_F^{0.418}(h_F) + h/2, & h/h_F < 0.5,\ d_F < 3.5 \\ 4.70(h_F) + h/2 & h/h_F < 0.5,\ d_F \geq 3.5 \end{array} \right\} & \text{torching tree option} \\ 1.055E^{1/2}, & \text{wind-driven surface fire option} \\ 12.2H_F, & \text{pile burning option} \end{cases}$$

where

$$h_F = \begin{cases} 16.5d^{0.515}n^{0.4}, & \text{grand fir, balsam fir} \\ 15.7d^{0.451}n^{0.4}, & \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlock} \\ 12.9d^{0.453}n^{0.4}, & \text{ponderosa pine, lodgepole pine, white pine} \end{cases}$$

$$d_F = \begin{cases} 12.6d^{-0.256}n^{-0.2}, & \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ 10.7d^{-0.278}n^{-0.2}, & \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ 6.3d^{-0.249}n^{-0.2}, & \text{western hemlock} \end{cases}$$

$f(U) = A\ (0.474\ U)^B$, where A and B are fuel model-dependent parameters (see table 1)

$$E = I \cdot f(U)$$

$$= \begin{cases} 7.18 \times 10^{-4}U\bar{h}^{*1/2}\left\{ 0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2} (1/2) \ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\}, & \text{torching tree, pile burning options} \\ 7.18 \times 10^{-4}U\bar{h}^{*1/2}\left\{ 0.362 + \left(\frac{z(0)}{\bar{h}^*}\right)^{1/2} (1/2) \ln\left(\frac{z(0)}{\bar{h}^*}\right)\right\} + 2.78 \times 10^{-4}Uz(0)^{0.643}, & \text{wind-driven surface fire option} \end{cases}$$

where

$$\bar{h}_c = 2.2z(0)^{0.337} - 4.0$$

$$\bar{h}^* = \max\ (\bar{h}, \bar{h}_c)$$

$= D \cdot X_6$,

where X_6 is from the iteration:

$$X_o = A$$

$$X_{n+1} = A - B\ (\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$$

$$A = F/D$$

$$B = H/(10\pi)$$

Equations Using Metric Units

$$z(0) = \left\{ \begin{array}{l} \left. \begin{array}{ll} 4.24 d_F^{0.332}(h_F) + h/2, & h/h_F \geq 1 \\ 3.64 d_F^{0.391}(h_F) + h/2, & 0.5 \leq h/h_F < 1 \\ 2.78 d_F^{0.418}(h_F) + h/2, & h/h_F < 0.5,\ d_F < 3.5 \\ 4.70(h_F) + h/2 & h/h_F < 0.5,\ d_F \geq 3.5 \end{array} \right\} \text{torching tree option} \\ 0.173E^{1/2}, \qquad \text{wind-driven surface fire option} \\ 12.2H_F, \qquad \text{pile burning option} \end{array} \right.$$

where

$$h_F = \begin{cases} 3.11 d^{0.515} n^{0.4}, & \text{grand fir, balsam fir} \\ 3.14 d^{0.451} n^{0.4}, & \text{Engelmann spruce, subalpine fir, Douglas-fir, western hemlo} \\ 2.58 d^{0.453} n^{0.4}, & \text{ponderosa pine, lodgepole pine, white pine} \end{cases}$$

$$d_F = \begin{cases} 16.0 d^{-0.256} n^{-0.2}, & \text{ponderosa pine, lodgepole pine, Engelmann spruce} \\ 13.9 d^{-0.278} n^{-0.2}, & \text{subalpine fir, Douglas-fir, balsam fir, grand fir, white pine} \\ 7.95 d^{-0.249} n^{-0.2}, & \text{western hemlock} \end{cases}$$

$f(U) = A\ (0.295\ U)^B,$ where A and B are fuel model-dependent parameters (see table 1)

$$E = I \cdot f(U)$$

$$F = \begin{cases} 1.30 \times 10^{-3} U \bar{h}^{*1/2} \left\{ 0.362 + \left(\frac{z(0)}{\bar{h}^*} \right)^{1/2} (\tfrac{1}{2}) \ln \left(\frac{z(0)}{\bar{h}^*} \right) \right\}, & \text{torching tree, pile burning options} \\ 1.30 \times 10^{-3} U \bar{h}^{*1/2} \left\{ 0.362 + \left(\frac{z(0)}{\bar{h}^*} \right)^{1/2} (\tfrac{1}{2}) \ln \left(\frac{z(0)}{\bar{h}^*} \right) \right\} + 5.03 \times 10^{-4} U z(0)^{0.643}, & \text{wind-driven surface fire option} \end{cases}$$

where

$$\bar{h}_c = z(0)^{0.337} - 1.22$$

$$\bar{h}^* = \max\ (\bar{h}, \bar{h}_c)$$

$S = D \cdot X_6,$

where X_6 is from the iteration:

$$X_o = A$$

$$X_{n+1} = A - B\ (\cos(\pi X_n - M\pi/2) - \cos(M\pi/2))$$

$$A = F/D$$

$$B = H/(10\pi)$$

THE TI-59 PROGRAM

The program for predicting maximum spot fire distance (Chase 1981) had to be extended to include spotting from wind-driven surface fires. Some user convenience in program operation was given up to obtain the advantage of having a single set of program cards, one set of operating instructions, and a single worksheet covering all options. In this revised version, the user may have to reenter up to three unchanged inputs to revise a single value. The user must also be careful to select reasonable data and enter those data without error since there are no checks on the validity of input data.

Maximum spot fire distance is predicted from three sources of firebrands: torching trees, burning piles, and wind-driven surface fires. Figure 1 is a chart showing program flow. Species data cards for the torching tree option from the original program (Chase 1981) contain data that are still valid, but the cards must be rerecorded under a new memory partition before being used with the revised version. Directions for rerecording these cards are given in the section entitled "Program Duplication."

The program is recorded on two cards (magnetic strips). A listing is in the appendix. A prerecorded copy of the program may be obtained by sending two blank magnetic cards for the TI-59 (eight cards if species data cards are also desired) to the author at the Northern Forest Fire Laboratory.

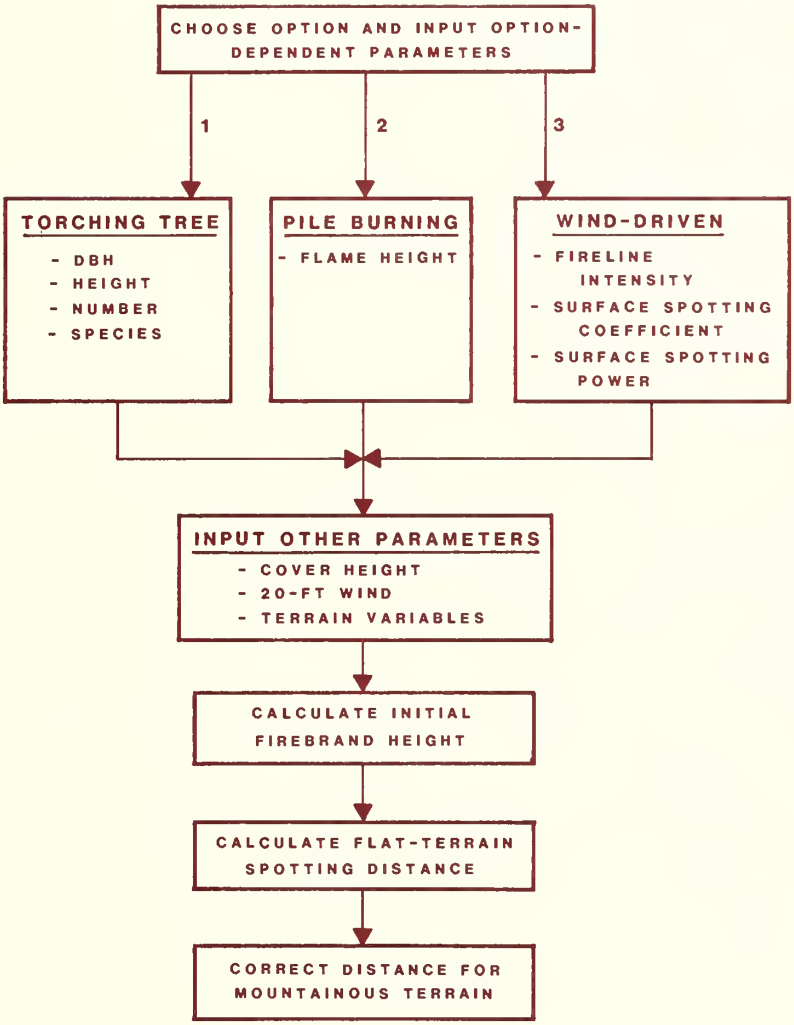


Figure 1.—This chart shows the general organization of the program to predict maximum spotting distance.

OPERATING INSTRUCTIONS

The program for calculating spot fire distance may be run on the TI-59 with any solid-state module in the calculator (such as NFDR/fire behavior module, library module, statistics module) or with no module in place.

Preliminaries

1. Turn on the calculator. (If it is already on, turn it off momentarily to clear program and memory registers.)

2. Partition memory before reading in the program. Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$. The display should read 639.39.

3. Press $\boxed{1}$. Feed side 1 of the program cards into the lower slot on the right side of the calculator. The motor will start and stop automatically. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 3.

4. Press $\boxed{2}$. Feed side 2 of the program into the slot. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 4.

5. Press $\boxed{3}$. Feed side 3 of the program into the slot. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 5.

Inputs

Record the necessary inputs on the worksheet (exhibit 1). Enter **one** of the following **three** groups of option-dependent inputs. The inputs in the selected group must be entered in the order given. The group number represents the option selected:

1. **Torching tree option:** Input of this group of values indicates choice of the torching tree option
   - —Enter diameter at breast height (d.b.h.) in inches of tree(s) torching out Press $\boxed{\text{A}}$
   - —Enter height in feet of tree(s) torching out Press $\boxed{\text{R/S}}$
   - —Enter the number of identical tree(s) burning at once to produce a single flame Press $\boxed{\text{R/S}}$
   - —A $\boxed{4}$ will appear in the display; feed in the tree species data card for the species desired
2. **Pile burning option:** Input of this value indicates choice of the pile burning option.
   - —Enter estimated flame height in feet from observation of continuous flame Press $\boxed{\text{B}}$
3. **Wind-driven surface fire option:** Input of this group of values indicates choice of the wind-driven surface fire option
   - —Enter the fireline intensity in Btu/ft/s (for assistance in obtaining this input, see section entitled "Estimating Fireline Intensities") Press $\boxed{\text{C}}$
   - —Enter the surface spotting coefficient (A) for the fuel model which represents your fuel complex (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom fuel models) Press $\boxed{\text{R/S}}$
   - —Enter surface spotting power (B) for your fuel model (see table 1 for models 1-7, 9-13; 1985 BEHAVE for custom models) Press $\boxed{\text{R/S}}$

Enter all of the following groups of inputs. Groups may be entered in any order, but inputs within a group must be entered in the order specified.

Name ____________________ Date ____________________ Sheet __________ of __________

Purpose ____

($\boxed{4}$ $\boxed{2nd}$ $\boxed{OP}$ $\boxed{1}$ $\boxed{7}$)

INPUTS

Option-dependent parameters	Reg. no.	Option Tree 1	Option Pile 2	Option Surface 3	Option Tree 1	Option Pile 2	Option Surface 3	Before entry	After entry
Torching tree d.b.h., inches	39	______			______				A
Torching tree height, ft	38	______			______				R/S
Number of trees torching together	37	______			______				R/S
Species	(read card)	______			______			4	
Continuous flame height, ft	31		______			______			B
Fireline intensity, Btu/ft/s	30			______			______		C
Surface spotting coefficient (A)	29			______			______		R/S
Surface spotting power (B)	28			______			______		R/S
Other parameters									
Mean cover height, ft	35	____________			____________				D
20-foot windspeed, mi/h	36	____________			____________				E
Ridge/valley elevational difference, ft	34	____________			____________				2nd A
Ridge/valley horizontal distance, mi	33	____________			____________				R/S
Spotting source location code	32	____________			____________				R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi	21	____________	____________	SBR =	

Exhibit 1.—Maximum Spotting Distance Worksheet

4. **Cover**

—Enter the mean cover height, in feet, of the area downwind of the firebrand source. Where timber or shrub cover exists, enter the height. If there is broken forest cover, enter one-half the treetop height of the forest-covered portion. If there is little or no forest cover (as is the case for option 3), enter vegetation height. This value is used to characterize the general forest cover as it influences the wind. Press $\boxed{\text{D}}$

5. **Wind**

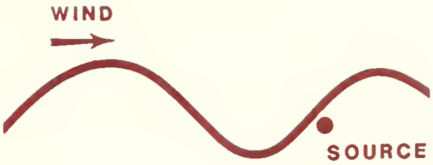
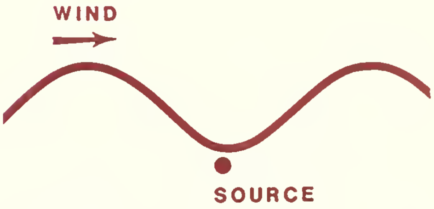
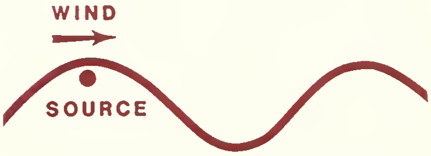
—Enter the average windspeed, in miles per hour, 20 feet above the vegetation Press $\boxed{\text{E}}$

6. **Terrain variables**

—If terrain is flat, enter zero here (do not skip this step—an incorrect nonzero value may be carried over from a previous run), then proceed to "Recall and Correction of Input". If terrain is not flat, enter average elevational difference in feet from ridge-top to valley bottom as would be shown on a map. (The model is not very sensitive to this input; rounding to nearest thousand is probably adequate.) The entry is in feet even though the equations use multiples of 1,000 feet. Press $\boxed{\text{2nd}}$ $\boxed{\text{A}}$

—Enter the ridgetop-to-valley bottom horizontal distance in miles as would be shown on a map. Press $\boxed{\text{R/S}}$

—Enter the firebrand source location code from the following list. Press $\boxed{\text{R/S}}$

Enter	**for**	
0	Midslope, windward side	
1	Valley bottom	
2	Midslope, leeward side	
3	Ridgetop	

Recall and Correction of Input

1. Recall flashing display of option number chosen by pressing $\boxed{\text{SBR}}$ $\boxed{\text{RCL}}$. If flashing 9's appear in the display, no option has been chosen. If a flashing 6 appears, more than one option has been chosen. Press $\boxed{\text{CLR}}$ to halt the flashing display. Press $\boxed{\text{SBR}}$ $\boxed{\text{CLR}}$ to clear option flags. Enter the group of option-dependent inputs desired and repeat this step.
2. Follow with a series of $\boxed{\text{R/S}}$ to view successive inputs for the selected option in the order listed on the worksheet. Items appearing in parentheses are not recalled (i.e., tree species in torching tree option is not recalled). The number of $\boxed{\text{R/S}}$ required for each option is:

Torching tree	8
Pile burning	6
Surface spotting	8

   If an additional $\boxed{\text{R/S}}$ is pushed, flashing 9's will appear in the display to signal the end of the recalled values. Press $\boxed{\text{CLR}}$ to halt the flashing display.
3. To change any item of input, reenter the group of inputs down through the correction for the wrong value as described in the input section.

Performing Calculations

1. Press $\boxed{\text{SBR}}$ $\boxed{=}$. When calculations are completed, the mountainous terrain spotting distance in miles will appear in the display. A flashing display at this point indicates an invalid calculation in the computation sequence. A list of conditions known to cause a flashing display here follows. There may be other causes.

Cause	Option	Flashing display
Windspeed = 0	1, 2, 3	0.00
Windspeed less than 0	1, 2, 3	Nonzero
Fireline intensity = 0	3	0.00
Custom model spotting coefficient = 0	3	0.00
Number of trees torching = 0	1	Nonzero
No option selected	1, 2, 3	9's
More than one option selected	1, 2, 3	6.00

Press $\boxed{\text{CLR}}$ to halt a flashing display and check your inputs.

Making Successive Runs

1. If changing options, press $\boxed{\text{SBR}}$ $\boxed{\text{CLR}}$ to clear option flags. Reenter group of option-dependent variables desired (group 1, 2, or 3).

2. Change one or more other groups of inputs by entering the group as described in input section. Then check entire input list, using $\boxed{\text{SBR}}$ $\boxed{\text{RCL}}$, $\boxed{\text{R/S}}$, $\boxed{\text{R/S}}$, ...

3. Perform calculations ($\boxed{\text{SBR}}$ $\boxed{=}$).

Following are some tips for users who don't wish to reenter valid inputs needlessly, but are willing to remember extra procedures:

1. If not changing options, the user can input a changed value manually by entering $\boxed{\text{value}}$ $\boxed{\text{STO}}$ $\boxed{\text{nn}}$ where nn is the register number where that value is stored (see exhibit 1).
2. Proceed to reinput the group of parameters, but stop after all changed values have been entered.
3. If changing options, but valid inputs from a prior run are still in place, input only the first value in the group of option-dependent parameters. This serves to set the option flag.

Name Sample Problems Date ______ Sheet 1 of 2

Purpose ______

(4 2nd OP 1 7)

INPUTS

Option-dependent parameters	Reg. no.	Tree ①	Option Pile 2	Surface 3	Tree 1	Option Pile ②	Surface 3	Before entry	After entry
Torching tree d.b.h., inches	39	20							A
Torching tree height, ft	38	137							R/S
Number of trees torching together	37	1							R/S
Species	(read card)	Grand fir						4	
Continuous flame height, ft	31					45			B
Fireline intensity, Btu/ft/s	30								C
Surface spotting coefficient (A)	29								R/S
Surface spotting power (B)	28								R/S
Other parameters									
Mean cover height, ft	35	130				100			D
20-foot windspeed, mi/h	36	20				15			E
Ridge/valley elevational difference, ft	34	4000				2000			2nd A
Ridge/valley horizontal distance, mi	33	.25				1			R/S
Spotting source location code	32	3				1			R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi	21	.31				.21		SBR =	

Exhibit 2a.—Maximum Spotting Distance Worksheet

Name Sample Problems Date ________ Sheet 2 of 2

Purpose ________

(4 2nd OP 1 7)

INPUTS

Option-dependent parameters	Reg. no.	Option Tree 1	Option Pile 2	Option Surface [✓ 3]	Option Tree 1	Option Pile 2	Option Surface [✓ 3]	Before entry	After entry
Torching tree d.b.h., inches	39								A
Torching tree height, ft	38								R/S
Number of trees torching together	37								R/S
Species	(read card)							4	
Continuous flame height, ft	31								B
Fireline intensity, Btu/ft/s	30	Fuel model 1		580	Fuel model 4		14 400		C
Surface spotting coefficient (A)	29			545			301		R/S
Surface spotting power (B)	28			-1.21			-1.05		R/S
Other parameters									
Mean cover height, ft	35			1			6		D
20-foot windspeed, mi/h	36			10			35		E
Ridge/valley elevational difference, ft	34			0			1000		2nd A
Ridge/valley horizontal distance, mi	33			-			.25		R/S
Spotting source location code	32			-			0		R/S

0=midslope, windward side
1=valley bottom
2=midslope, leeward side
3=ridgetop

OUTPUT

Maximum spotting distance corrected for mountainous terrain, mi	21	0.27	1.58	SBR =	

Exhibit 2b.—Maximum Spotting Distance Worksheet

ESTIMATING FIRELINE INTENSITIES

You may wish to use fire behavior calculations (Burgan 1979) to produce realistic fireline intensity values for input to the spot fire program. In this case, the NFDR/fire behavior CROM (custom read only memory) must be in place.

Switching from calculator to module memory (from spot fire distance to fire behavior calculations) and vice versa causes memory problems due to partitioning. Overcoming the problems involves a cumbersome procedure. Therefore it is recommended that the user make all the runs he/she wishes using one program, momentarily turn the calculator off and then on again, then access the other program (by pressing $\boxed{\text{2nd}}$ $\boxed{\text{PGM}}$ $\boxed{2}$ $\boxed{\text{SBR}}$ $\boxed{\text{R/S}}$ [see Burgan 1979] or by reading the program cards) to make the desired runs.

Note that 20-foot windspeed is the input for the spot fire program, while midflame windspeed is used for fire behavior. Refer to Rothermel (1983) for guidelines in adjusting windspeeds.

Another method of estimating fireline intensity for real-time predictions is to use observed flame lengths in Byram's (1959) formula, which relates fireline intensity and flame length:

$$I = 5.66L^{2.17}$$

where

I = fireline intensity, Btu/ft/s
L = flame length, ft

SAMPLE PROBLEMS

Exhibits 2a and 2b contain the inputs and outputs for four examples — one for torching tree option, one for pile burning, and two for the surface spot fire option.

CONDENSED INSTRUCTIONS

reliminaries

1. $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
2. Press $\boxed{1}$, feed side 1 (flashing: $\boxed{\text{CLR}}$, try again).
3. Press $\boxed{2}$, feed side 2 (flashing: $\boxed{\text{CLR}}$, try again).
4. Press $\boxed{3}$, feed side 3 (flashing: $\boxed{\text{CLR}}$, try again).

put

Enter		**Press**
	Torching tree d.b.h.	$\boxed{\text{A}}$
Group 1	Torching tree height	$\boxed{\text{R/S}}$
	No. trees torching together	$\boxed{\text{R/S}}$
	Read species card	
or		
Group 2	Observed flame height	$\boxed{\text{B}}$
or		
	Fireline intensity	$\boxed{\text{C}}$
Group 3	Surface spotting coefficient (A)	$\boxed{\text{R/S}}$
	Surface spotting power (B)	$\boxed{\text{R/S}}$
Group 4	Mean cover height	$\boxed{\text{D}}$
Group 5	20-foot windspeed	$\boxed{\text{E}}$
	Ridge/valley elevational difference	$\boxed{\text{2nd}}$ $\boxed{\text{A}}$
Group 6	Ridge/valley horizontal distance	$\boxed{\text{R/S}}$
	Firebrand source location code	$\boxed{\text{R/S}}$

Check Inputs $\boxed{\text{SBR}}\boxed{\text{RCL}}$; follow by series of $\boxed{\text{R/S}}$

Calculations $\boxed{\text{SBR}}\boxed{=}$

To Clear Option Flags $\boxed{\text{SBR}}\boxed{\text{CLR}}$

REGISTER ASSIGNMENTS

For completeness, the following list gives memory locations assigned to the inputs, outputs, and selected intermediate values.

Register	Symbol	Contents
39	d	Torching tree d.b.h.
38	h	Torching tree height
37	n	Number of trees torching together
31	H_F	Continuous flame height
30	I	Fireline intensity
29	A	Surface spotting coefficient
28	B	Surface spotting power
35	$\bar{h}$	Mean cover height
36	U	20-foot windspeed
34	1000H	Ridge/valley elevation difference
33	D	Ridge/valley horizontal distance
32	M	Spotting source location code
17	$\bar{h}^*$	Cover height used in calculations
16	none	Downwind drift during lofting
25	z(0)	Initial firebrand height
26	d_F	Adjusted steady flame duration
27	h_F	Adjusted steady flame height
24	F	Flat terrain spotting distance
21	S	Corrected spotting distance

PROGRAM DUPLICATION

The program recorded on one set of magnetic cards can be duplicated on another blank set as follows:

Program Cards

1. Turn on your calculator. Enter the program into memory using the set of cards to be duplicated.

$\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$

$\boxed{1}$; feed side 1 (if flashing; press $\boxed{\text{CLR}}$, try again)

$\boxed{2}$; feed side 2 (if flashing; press $\boxed{\text{CLR}}$, try again)

$\boxed{3}$; feed side 3 (if flashing; press $\boxed{\text{CLR}}$, try again)

2. Press $\boxed{1}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 1 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 2.

3. Press $\boxed{2}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 2 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 3.

4. Press $\boxed{3}$ $\boxed{\text{2nd}}$ $\boxed{\text{R/S}}$ and feed in side 3 of the set of blank cards. If the display flashes, press $\boxed{\text{CLR}}$ and repeat step 4.

5. Label the cards appropriately, using a pen with permanent, fast-drying ink. A suggestion for labeling is shown in figure 2.

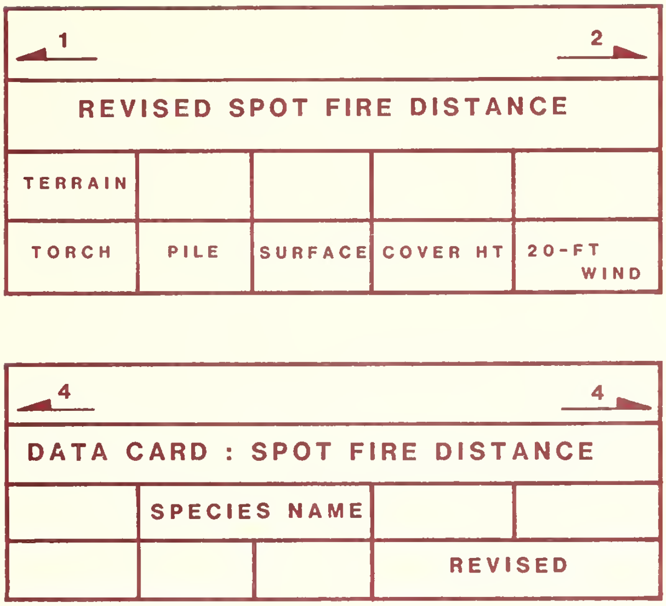


Figure 2.—Suggested labeling for spot fire program cards.

ata Cards

To re-record data cards for original program under new partition for revised program.

1. Turn on calculator.
2. Read card for original program:
   Press $\boxed{4}$; feed card (either side) (if flashing; press $\boxed{\text{CLR}}$, try again).
3. Repartition memory: $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
4. Re-record:
   Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{WRITE}}$; feed card; (if flashing; press $\boxed{\text{CLR}}$, try again)
   Repeat step 4 for all sides of cards for this species.
5. Label the card appropriately (see fig. 2).
6. If there are data cards for another species to re-record:
   $\boxed{6}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$
   Repeat steps 2-5.

To duplicate valid data cards for the revised program:

1. Turn on calculator.
   Repartition memory: $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\text{OP}}$ $\boxed{1}$ $\boxed{7}$

2. Press $\boxed{4}$ and feed in one side of the data card to be duplicated. If the display flashes, press $\boxed{\text{CLR}}$ and try again.

3. Press $\boxed{4}$ $\boxed{\text{2nd}}$ $\boxed{\overline{\text{RS}}}$ and feed in one side of the blank card. If the display flashes, try again. Repeat step 3 for the other side of the blank card.

4. Label the card appropriately (see fig. 2).
   Repeat steps 2 through 4 for remaining data cards.

REFERENCES

Albini, Frank A. Estimating wildfire behavior and effects. Gen. Tech. Rep. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 92 p.

Albini, Frank A. Spot fire distance from burning trees—a predictive model. Gen. Tech. Rep. INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979, 73 p.

Albini, Frank A. Spot fire distance from isolated sources—extensions of a predictive model. Res. Note INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 9 p.

Albini, Frank A. Potential spotting distance from wind-driven surface fires. Res. Pap. INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 27 p.

Anderson, Hal E. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 22 p.

Andrews, Patricia L. A system for predicting the behavior of forest and range fires. In: Proceedings, 1983 SCS conference on computer simulation in emergency planning; 1983 January 27-29; San Diego, CA. LaJolla, CA: Simulation Councils, Inc.; 1983: 75-78.

Andrews, Patricia L. BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory; review draft.

Burgan, Robert E. Fire danger/fire behavior computations with the Texas Instruments TI-59 calculator: user's manual. Gen. Tech. Rep. INT-61. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 25 p.

Burgan, Robert E.; Rothermel, Richard C. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. Gen. Tech. Rep. INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 126 p.

Byram, G. M. Combustion of forest fuels. In: Davis, Kenneth P., ed. Forest fire control and use. New York: McGraw-Hill; 1959: 90.

Catchpole, Wendy R. [Letter to Dick Rothermel]. 1983 October 31. Located at: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, MT; RWU 2103 files.

Chase, Carolyn H. Spot fire distance equations for pocket calculators. Res. Note INT-310. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 21p.

Rothermel, Richard C. How to predict the spread and intensity of forest and range fires. Gen. Tech. Rep. INT-143. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 161 p.

Roussopoulos, Peter J.; Johnson, Von J. Help in making fuel management decisions. Res. Pap. NC-112. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1975. 16 p.

PPENDIX
ROGRAM LISTING

```
000  25  CLR
001  91  R/S
002  76  LBL
003  22  INV
004  53  (
005  43  RCL
006  01   01
007  65  ×
008  43  RCL
009  39   39
010  45  Yˣ
011  43  RCL
012  02   02
013  65  ×
014  43  RCL
015  37   37
016  45  Yˣ
017  93  .
018  04   4
019  54  )
020  53  (
021  42  STO
022  27   27
023  35  1/X
024  65  ×
025  43  RCL
026  38   38
027  54  )
028  32  X↕T
029  01   1
030  22  INV
031  77   GE
032  23  LNX
033  93  .
034  05   5
035  22  INV
036  77   GE
037  24  CE
038  43  RCL
039  26   26
040  32  X↕T
041  03   3
042  93  .
043  05   5
044  77   GE
045  32  X↕T
046  01   1
047  01   1
048  42  STO
049  23   23
050  01   1
051  02   2
052  42  STO
053  22   22
054  61  GTO
055  47  CMS
056  76  LBL
057  32  X↕T
058  09   9
059  42  STO
060  23   23
061  01   1
062  00   0
063  42  STO
064  22   22
065  61  GTO
066  47  CMS
067  76  LBL
068  24  CE
069  07   7
070  42  STO
071  23   23
072  08   8
073  42  STO
074  22   22
075  61  GTO
076  47  CMS
077  76  LBL
078  23  LNX
079  05   5
080  42  STO
081  23   23
082  06   6
083  42  STO
084  22   22
085  76  LBL
086  47  CMS
087  92  RTN
088  76  LBL
089  34  √X
090  53  (
091  43  RCL
092  03   03
093  65  ×
094  43  RCL
095  39   39
096  45  Yˣ
097  43  RCL
098  04   04
099  65  ×
100  43  RCL
101  37   37
102  45  Yˣ
103  93  .
104  02   2
105  94  +/-
106  54  )
107  42  STO
108  26   26
109  92  RTN
110  76  LBL
111  35  1/X
112  71  SBR
113  22  INV
114  71  SBR
115  34  √X
116  76  LBL
117  33  X²
118  53  (
119  73  RC*
120  23   23
121  65  ×
122  43  RCL
123  26   26
124  45  Yˣ
125  73  RC*
126  22   22
127  65  ×
128  43  RCL
129  27   27
130  85  +
131  43  RCL
132  38   38
133  55  ÷
134  02   2
135  54  )
136  61  GTO
137  42  STO
138  76  LBL
139  44  SUM
140  53  (
141  01   1
142  02   2
143  93  .
144  02   2
145  65  ×
146  43  RCL
147  31   31
148  54  )
149  61  GTO
150  42  STO
151  76  LBL
152  45  Yˣ
153  43  RCL
154  35   35
155  32  X↕T
156  53  (
157  02   2
158  93  .
159  02   2
160  65  ×
161  43  RCL
162  25   25
163  45  Yˣ
164  93  .
165  03   3
166  03   3
167  07   7
168  75  -
169  04   4
170  54  )
171  22  INV
172  77   GE
173  52  EE
174  42  STO
175  17   17
176  92  RTN
177  76  LBL
178  52  EE
179  32  X↕T
180  42  STO
181  17   17
182  92  RTN
183  76  LBL
184  53  (
185  53  (
186  93  .
187  00   0
188  00   0
189  00   0
190  07   7
191  01   1
192  08   8
193  65  ×
194  43  RCL
195  36   36
196  65  ×
197  43  RCL
198  17   17
199  34  √X
200  65  ×
201  53  (
202  93  .
203  03   3
204  06   6
205  02   2
206  85  +
207  53  (
208  43  RCL
209  25   25
210  55  ÷
211  43  RCL
212  17   17
213  54  )
214  34  √X
215  55  ÷
216  02   2
217  65  ×
218  53  (
219  43  RCL
220  25   25
221  55  ÷
222  43  RCL
223  17   17
224  54  )
225  23  LNX
226  54  )
227  54  )
228  42  STO
229  24   24
230  92  RTN
231  76  LBL
232  54  )
233  53  (
234  53  (
235  93  .
236  00   0
237  00   0
238  00   0
239  02   2
240  07   7
241  08   8
242  65  ×
243  43  RCL
244  36   36
245  65  ×
246  43  RCL
247  25   25
248  45  Yˣ
249  93  .
250  06   6
251  04   4
252  03   3
253  54  )
254  42  STO
255  16   16
256  85  +
257  43  RCL
258  24   24
259  54  )
260  42  STO
261  24   24
262  61  GTO
263  55  ÷
264  76  LBL
265  95  =
266  58  FIX
267  02   02
268  87  IFF
269  01   01
270  65  ×
271  87  IFF
272  02   02
273  93  .
274  22  INV
275  87  IFF
276  03   03
277  36  PGM
278  61  GTO
279  75  -
280  76  LBL
281  65  ×
282  87  IFF
283  02   02
284  30  TAN
```

```
285  76 LBL
286  93  .
287  87 IFF
288  03  03
289  30 TAN
290  61 GTO
291  75  -
292  76 LBL
293  30 TAN
294  03  3
295  06  6
296  94 +/-
297  34 √X
298  91 R/S
299  76 LBL
300  36 PGM
301  00  0
302  35 1/X
303  91 R/S
304  76 LBL
305  75  -
306  87 IFF
307  01  01
308  35 1/X
309  87 IFF
310  02  02
311  44 SUM
312  53  (
313  53  (
314  53  (
315  43 RCL
316  29  29
317  65  ×
318  53  (
319  93  .
320  04  4
321  07  7
322  04  4
323  65  ×
324  43 RCL
325  36  36
326  54  )
327  45 Yˣ
328  43 RCL
329  28  28
330  54  )
331  65  ×
332  43 RCL
333  30  30
334  54  )
335  34 √X
336  65  ×
337  01  1
338  93  .
339  00  0
340  05  5
341  05  5
342  54  )
343  76 LBL
344  42 STO
345  42 STO
346  25  25
347  71 SBR
348  45 Yˣ
349  71 SBR
350  53  (
351  87 IFF
```

```
352  03  03
353  54  )
354  76 LBL
355  55  ÷
356  00  0
357  32 X↕T
358  43 RCL
359  33  33
360  67  EQ
361  85  +
362  43 RCL
363  34  34
364  67  EQ
365  85  +
366  53  (
367  43 RCL
368  24  24
369  55  ÷
370  43 RCL
371  33  33
372  54  )
373  42 STO
374  20  20
375  42 STO
376  19  19
377  53  (
378  43 RCL
379  34  34
380  55  ÷
381  01  1
382  00  0
383  00  0
384  00  0
385  00  0
386  55  ÷
387  89  π
388  54  )
389  42 STO
390  18  18
391  06  6
392  42 STO
393  00  00
394  76 LBL
395  61 GTO
396  53  (
397  43 RCL
398  20  20
399  75  -
400  43 RCL
401  18  18
402  65  ×
403  53  (
404  53  (
405  01  1
406  08  8
407  00  0
408  65  ×
409  43 RCL
410  19  19
411  75  -
412  43 RCL
413  32  32
414  65  ×
415  09  9
416  00  0
417  54  )
418  39 COS
```

```
419  75  -
420  53  (
421  43 RCL
422  32  32
423  65  ×
424  09  9
425  00  0
426  54  )
427  39 COS
428  54  )
429  54  )
430  42 STO
431  19  19
432  97 DSZ
433  00  00
434  61 GTO
435  53  (
436  43 RCL
437  19  19
438  65  ×
439  43 RCL
440  33  33
441  54  )
442  42 STO
443  21  21
444  91 R/S
445  76 LBL
446  85  +
447  43 RCL
448  24  24
449  42 STO
450  21  21
451  91 R/S
452  76 LBL
453  43 RCL
454  87 IFF
455  01  01
456  71 SBR
457  87 IFF
458  02  02
459  37 P/R
460  22 INV
461  87 IFF
462  03  03
463  48 EXC
464  61 GTO
465  38 SIN
466  76 LBL
467  71 SBR
468  87 IFF
469  02  02
470  39 COS
471  76 LBL
472  37 P/R
473  87 IFF
474  03  03
475  39 COS
476  61 GTO
477  38 SIN
478  76 LBL
479  39 COS
480  03  3
481  06  6
482  94 +/-
483  34 √X
484  91 R/S
485  76 LBL
```

```
486  48 EXC
487  00  0
488  35 1/X
489  91 R/S
490  76 LBL
491  38 SIN
492  87 IFF
493  01  01
494  94 +/-
495  87 IFF
496  02  02
497  28 LOG
498  09  9
499  94 +/-
500  34 √X
501  91 R/S
502  43 RCL
503  30  30
504  91 R/S
505  43 RCL
506  29  29
507  91 R/S
508  43 RCL
509  28  28
510  91 R/S
511  76 LBL
512  29 CP
513  43 RCL
514  35  35
515  91 R/S
516  43 RCL
517  36  36
518  91 R/S
519  43 RCL
520  34  34
521  91 R/S
522  43 RCL
523  33  33
524  91 R/S
525  43 RCL
526  32  32
527  91 R/S
528  00  0
529  35 1/X
530  91 R/S
531  76 LBL
532  94 +/-
533  01  1
534  94 +/-
535  34 √X
536  91 R/S
537  43 RCL
538  39  39
539  91 R/S
540  43 RCL
541  38  38
542  91 R/S
543  43 RCL
544  37  37
545  91 R/S
546  61 GTO
547  29 CP
548  76 LBL
549  28 LOG
550  04  4
551  94 +/-
552  34 √X
```

```
553  91 R/S
554  43 RCL
555  31  31
556  91 R/S
557  61 GTO
558  29 CP
559  76 LBL
560  11  A
561  86 STF
562  01  01
563  42 STO
564  39  39
565  91 R/S
566  42 STO
567  38  38
568  91 R/S
569  42 STO
570  37  37
571  04  4
572  91 R/S
573  76 LBL
574  12  B
575  86 STF
576  02  02
577  42 STO
578  31  31
579  91 R/S
580  76 LBL
581  13  C
582  86 STF
583  03  03
584  42 STO
585  30  30
586  91 R/S
587  42 STO
588  29  29
589  91 R/S
590  42 STO
591  28  28
592  91 R/S
593  76 LBL
594  14  D
595  42 STO
596  35  35
597  91 R/S
598  76 LBL
599  15  E
600  42 STO
601  36  36
602  91 R/S
603  76 LBL
604  16  A'
605  42 STO
606  34  34
607  91 R/S
608  42 STO
609  33  33
610  91 R/S
611  42 STO
612  32  32
613  91 R/S
614  76 LBL
615  25 CLR
616  81 RST
```

CORRECTED VALUES

Table A.—Corrected values of the standard deviation of fire intensity, as a percentage of the mean intensity (coefficient of variation) for 12 fuel models that occur without timber cover (supersedes Albini, 1983, table 3).

Fuel model	Mean horizontal windspeed at 10 m ht, m/s					
	5	10	15	20	25	30
Grass and litter						
1 Short grass	37.5	27.9	22.0	18.0	15.0	12.8
2 Grassy understory	56.5	45.6	37.3	31.0	26.1	22.4
3 Tall grass	49.1	35.9	27.2	21.3	17.2	14.2
9 Hardwood litter	70.4	63.3	56.2	49.8	44.3	39.6
Shrub types						
4 Mature chaparral	40.0	24.9	17.3	13.0	10.3	8.42
5 Young chaparral	24.4	14.1	10.0	7.75	6.32	5.33
6 Dormant brush	48.9	33.1	24.2	18.8	15.3	12.8
7 Southern rough	43.4	27.6	19.9	15.4	12.5	10.5
Logging slash						
10 Overgrown slash	55.1	39.7	30.3	24.4	20.3	17.4
11 Light conifer slash	52.1	35.5	26.5	21.0	17.4	14.8
12 Medium conifer slash	50.1	33.4	24.6	19.3	15.9	13.4
13 Heavy conifer slash	49.6	32.5	23.8	18.7	15.4	13.0

Following are corrected example calculations (Albini 1983) using the author's equation numbers and nomenclature.

Example 1.

$$f(U) = AU^{B} = 545 \times (5)^{-1.21} = 77.7\ \mathrm{s} \qquad (9)$$

$$E = I\ f(U) = (2000)(77.7) = 155\ 400\ \mathrm{kJ/m} \qquad (10)$$

$$H = 0.173\ E^{1/2} = (0.173)(155\ 400)^{1/2} = 68.2\ \mathrm{m} \qquad (11)$$

$$2.93\ \mathrm{m} = \text{effective cover height}$$

$$F = \text{flat terrain spotting distance} = 0.30\ \mathrm{km} \qquad (13)$$

$$U(68) = U(10\mathrm{m}) \times \left(\frac{68}{10}\right)^{1/7} = (5)(1.32) = 6.6\ \mathrm{m/s} \qquad (14)$$

$$X = (2.78)(6.6)(68.2)^{1/2} = 151\ \mathrm{m} = 0.151\ \mathrm{km} \qquad (15)$$

$$\text{Spotting distance} = 0.30 + 0.15 = 0.45\ \mathrm{km}$$

Example 2.

$$f(U) = AU^{B} = 301\ (20)^{-1.05} = 13.0\ \mathrm{s} \qquad (16)$$

$$E = I\ f(U) = (50\ 000)(13.0) = 650\ 000\ \mathrm{kJ/m} \qquad (17)$$

$$H = 0.173\ E^{1/2} = (0.173)(806) = 139\ \mathrm{m} \qquad (18)$$

$$F = 1.87\ \mathrm{km}$$

$$U(139) = U(10) \times \left(\frac{139}{10}\right)^{1/7} = 29.1\ \mathrm{m/s} \qquad (19)$$

$$X = (2.78)(29.1)(139)^{1/2} = 954\ \mathrm{m} = 0.954\ \mathrm{km} \qquad (20)$$

$$\text{Spotting distance} = 1.87 + 0.95 = 2.82\ \mathrm{km}$$

*U.S. GOVERNMENT PRINTING OFFICE: 1984-0-576-040/10,520

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

nited States
epartment of
griculture

orest Service

termountain
orest and Range
xperiment Station
gden, UT 84401

esearch Note
IT-347

ctober 1984

Viability of Seed Produced on Highly Sodic Coal Mine Spoils

Bland Z. Richardson
Walter T. McDonough
Eugene E. Farmer[1]

BSTRACT

An "adapted" plant species must not only grow on a articular site, but also produce viable seeds capable f germination and establishment on the site. Ten species f rangeland grasses had been successfully used to evegetate sodic mine spoils at the Decker Coal Mine southeastern Montana. However, the effect of the odic spoils on seed viability, and hence the potential or regeneration, was unknown. Seeds produced by hese plants were tested for viability and germination. esults indicated regeneration of seven of the 10 species ould not be affected by sodic spoil material. The esponses of the other three species were significantly ower.

EYWORDS: surface mine revegetation, seed viability, germination, rangeland grasses, vegetative cover, sodic mine spoils

One consequence of surface mining for coal is the ed to establish vegetation on spoil areas. Establishment plant cover requires devising effective treatments d subsequent management for a variety of surface ined land types. Sodic mine spoils, those containing excess of exchangeable sodium, may require special anagement treatments to establish vegetation. Seed oduction, viability, and germination are critical to ant establishment. Environmental conditions that inence these processes may determine the perpetuation, d hence the importance, of a plant species, particularly der stresses that may be severe on highly sodic mine oils (Richardson and Farmer 1982). Therefore, the tential viability and germination of seeds produced grass species successfully growing in these conditions re examined.

METHODS AND MATERIALS

Revegetation research was begun on the spoil area of the Decker Coal Mine in southeastern Montana in 1972. Average annual precipitation in the area is 15.43 inches (39.2 cm). A succession of smooth divides and broad drainage bottoms of rolling land with buttes of red scoria and shale outcrops comprise the general physiography. The soils are clayey Ustic Aridsols having large amounts of sodium on the clay particles.

Sodic spoil materials from the mine dumps were used for these studies. The research involved several varied treatments using native and introduced grass species. In 1975 an attempt was made to learn whether the species planted had the potential to be self-perpetuating on the spoils. By that time it was apparent that 10 species could successfully grow at the site, but it was unknown whether they were producing viable seeds. Species used in the study were: intermediate wheatgrass (*Agropyron intermedium*); Fairway crested wheatgrass (*A. cristatum*); smooth brome (*Bromus inermis*); pubescent wheatgrass (*A. trichophorum*); Russian wildrye (*Psathyrostachys juncea*); western wheatgrass (*A. smithii*); tall wheatgrass (*A. elongatum*); green needlegrass (*Stipa viridula*); winter rye (*Secale cereale*); and slender wheatgrass (*A. trachycaulum*).

Field collections of seeds produced by the grasses on the mine spoils were separated, cleaned, and packaged by species. Determinations included: (1) estimates of potential germination using the tetrazolium color reaction test of the embryo (McDonough 1974); (2) optimum temperatures for germination of each species; and (3) time in days required for completion of germination.

Percentage seed germination was determined by methods described in detail by McDonough (1969). Germination tests were made for eight replications of 50 seeds for each of the 10 species. Tests were conducted

---

Research forester, plant physiologist, and forest hydrologist, respectively, ited at the Intermountain Station's Forestry Sciences Laboratory, an, UT.

in 9-cm Petri dishes lined with two sheets of Whatman #1 filter paper[2] saturated with 3.5 ml distilled water. Seeds in each replication were uniformly distributed over the filter paper. Effects of temperature alternation on germination were tested in Lab-line germinators. Temperature combinations tested were: 30/20° C; 25/15° C; and 15/5° C with each temperature maintained for 12 hours. Cool white fluorescent lamps provided light intensity of 1100 lumens/m^2. Light periods coincided with the periods of higher temperature. Rates of germination at the optimum temperature alternation were determined for the nine species having total germination of approximately 20 percent or more at the optimum temperature.

RESULTS AND DISCUSSION

Measures of potential seed viability, indicated by the red color of the embryo resulting from the tetrazolium tests, ranged from 74 percent to 100 percent, as shown in the following tabulation:

Species	**Viability**
Intermediate wheatgrass (*Agropyron intermedium*)	100
Fairway crested wheatgrass (*A. cristatum*) .	96
Smooth brome (*Bromus inermis*)	96
Pubescent wheatgrass (*A. trichophorum*) .	94
Russian wildrye (*Psathyrostachys juncea*) .	86
Western wheatgrass (*A. smithii*)	86
Tall wheatgrass (*A. elongatum*)	84
Green needlegrass (*Stipa viridula*)	78
Winter rye (*Secale cereale*)	76
Slender wheatgrass (*A. trachycaulum*) . .	74

The optimum temperature combination was 25/15° for crested, pubescent, tall, and intermediate wheatgrasses. For slender and western wheatgrasses, needl grass, wildrye, and winter rye the optimum temperatu combination was 15/5° C. Performance of the species at the three temperature combinations is shown in figure 1. At the optimum temperature, germination o 60 to 90 percent was reached by the sixth day in six of the nine species tested and germination was complet by the 10th day in all species (fig. 2).

The percentages and rates of germination for intermediate, crested, pubescent, western, and tall wheatgrasses, smooth brome, and Russian wildrye indicate that viability and germinability of seeds produced by these species were not affected by parent plant growt on sodic spoil conditions to an extent that would cau failure to establish and perpetuate a vegetative cover. The low percentages and rates of germination for slen wheatgrass, green needlegrass, and winter rye sugges that optimum conditions for germination of these speci were not provided during the tests. However, the rel tively high values (78, 74, and 76 percent, respective for the tetrazolium viability tests indicate these grasse have a good potential to perpetuate themselves on th sodic spoils at the Decker Coal Mine by seed productio Results of this study further indicate that viability of seed produced by the plants when grown on these spo equals that of seeds produced in a normal environme (Baldridge and Lohmiller, in press).

---

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

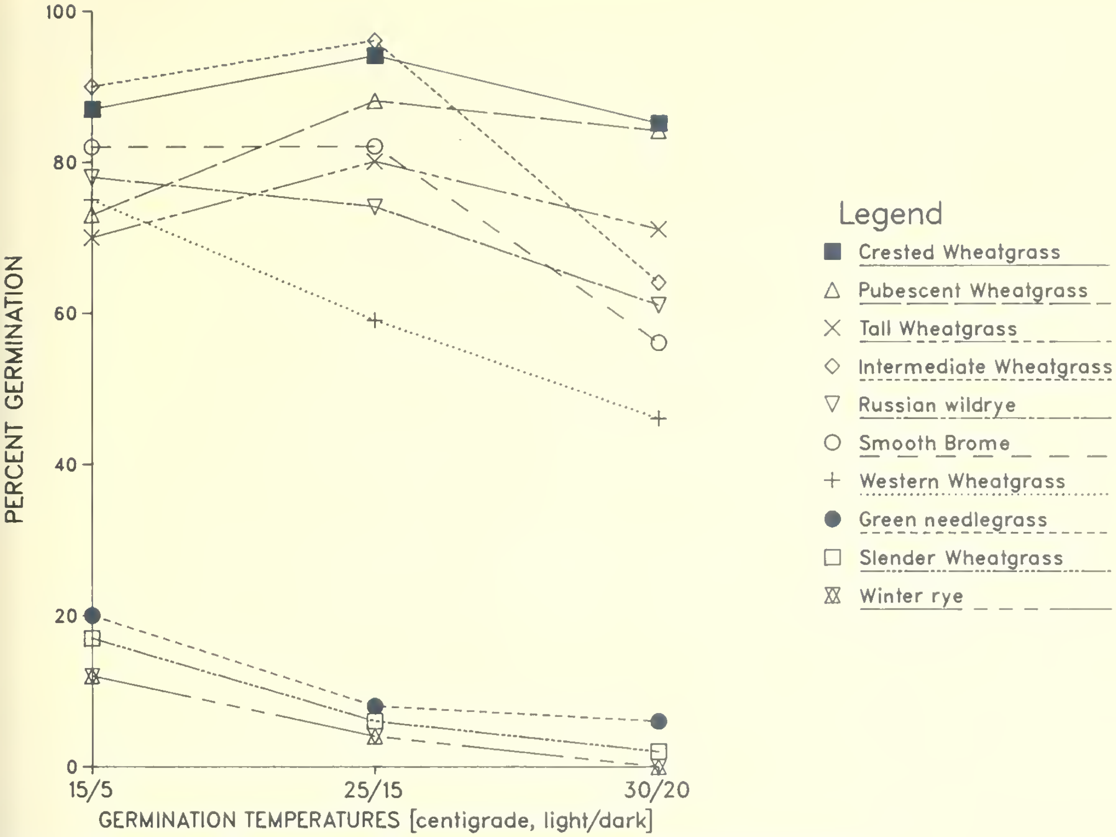


Figure 1.—Germination of seeds from 10 grasses growing on sodic mine spoils at three temperature alternations.

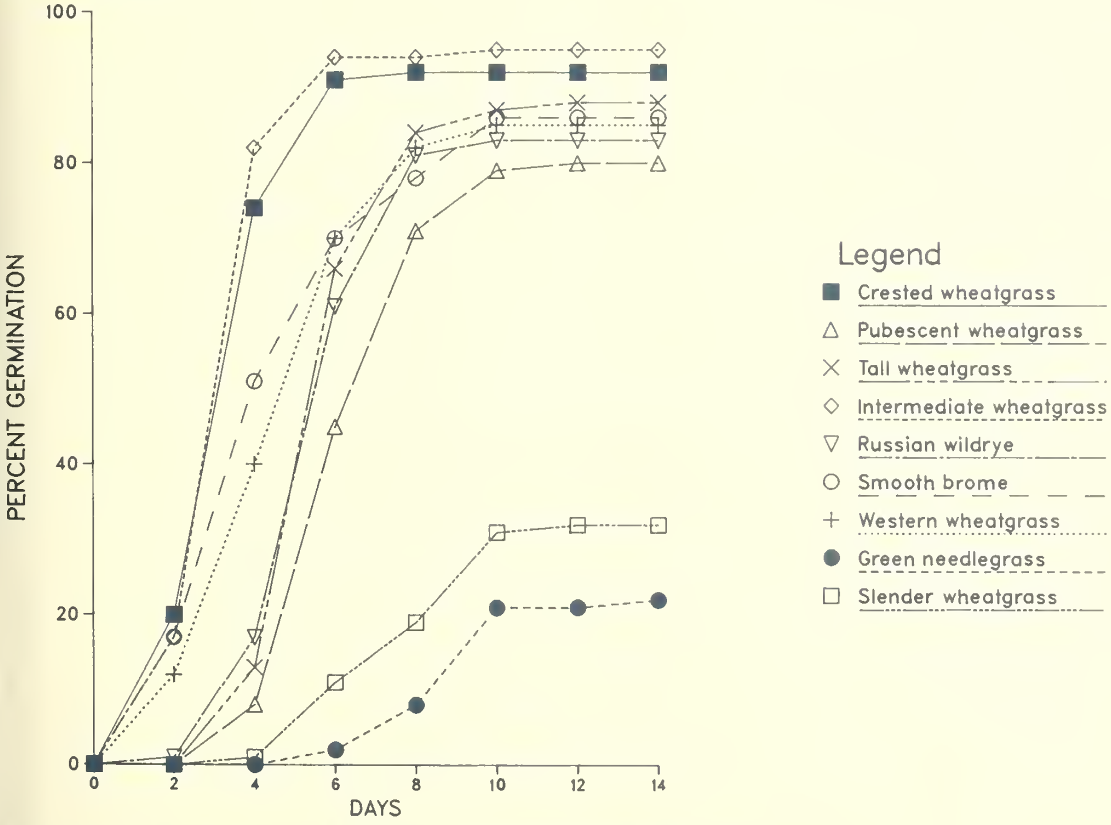


FIG. 2. Percent germination and germination times at optimum temperatures for eight grass species grown on sodic mine spoils.

Figure 2.—Percent germination and germination times at optimum temperatures for eight grass species grown on sodic mine spoils.

REFERENCES

Baldridge, D. E.; Lohmiller, R. G., eds. Montana interagency plant materials handbook for forage production, conservation, reclamation, and wildlife. Bozeman, MT: Montana Cooperative Extension Service; [in press]

McDonough, Walter T. Effective treatments for the introduction of germination in mountain rangeland species. Northwest Science. 43(1): 18-22; 1969.

McDonough, Walter T. Tetrazolium viability, germinability, and seedling growth of old seeds of 36 mountain range plants. Research Note INT-185. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountian Forest and Range Experiment Station; 1974. 6 p.

Richardson, Bland Z.; Farmer, Eugene E. Changes in sodium adsorption ratios following revegetation of coal mine spoils in southeastern Montana. Research Paper INT-287. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountian Forest and Range Experiment Station; 1982. 4 p.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

U S GOVERNMENT PRINTING OFFICE: 1984—776-032/10513 REGION NO. 8

ited States
epartment of
riculture

ermountain
rest and Range
periment Station
jden, UT 84401

esearch Note
T-348

tober 1984

A Passive Aerial Barrier Trap Suitable for Sampling Flying Bark Beetles

Richard F. Schmitz[1]

BSTRACT

An inexpensive, 4-lb (1.8-kg), omnidirectional passive
rrier trap of clear Plexiglas is used to census flying
rk beetles, especially the mountain pine beetle, Den-
octonus ponderosae. *The lightweight plastic compo-*
nts allow three traps to be suspended from a single
rtical nylon line, using only tree limbs for support,
levels ranging to midcrown. The vertical line, with
ıp, is supported by a nylon line positioned in adjacent
e crowns with a bow and arrow or line gun. The
sign does not use sticky trapping surfaces, thereby
minating the need to restick traps and reducing the
ne needed to recover and identify the catch. Insects
ught during one season by order were Coleoptera 49
rcent (Scolytidae 18 percent), Hemiptera 14 percent,
ptera 14 percent, Hymenoptera 8 percent, Lepidoptera
percent, Homoptera 4 percent, Neuroptera 1 percent,
d Orthoptera, Ephemeroptera, and Trichoptera <1
rcent.

EYWORDS: Scolytidae, bark beetles, omnidirectional passive barriertrap, *Dendroctonus ponderosae*, associated insects

Determining the relative abundance of in-flight populations of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Coleoptera: Scolytidae) is one measure of the effectiveness of partial cuts designed to reduce tree killing in lodgepole pine stands. The population measurements require a suitable passive trap (Schmitz and others 1980). Little is known of the vertical stratification of flying populations of the beetle, except that within 20 ft (6 m) of the ground most fly 8 to 16 ft (2.4 to 4.9 m) above ground (Avis 1971). Tree heights exceeded the 20-ft (6-m) level because the partial cuts were made in mature lodgepole pine stands. Consequently, there was need to determine whether beetles flew above the 20-ft stratum. This required a trap suitable to intercept in-flight populations at three heights ranging to midcrown without using attractants that might disrupt the natural distribution or density of the populations to be measured.

Specifically, the desired measures required an inexpensive passive trap with a barrier surface area comparable to existing designs. But the traps needed to be lighter so that several could be suspended from a single support, without need to climb the support tree or erect bulky or expensive supporting apparatus. Additionally, the trap would need to be left unattended for a week at a time and still preserve the catch in a readily identifiable condition. Yet it had to be portable and sufficiently durable for transporting to remote forest locations and assembling without tools.

In general, window and sticky traps have proven most effective for sampling flying scolytids (Chapman and Kinghorn 1955; Juillet 1963; Hosking and Knight 1975; Hosking 1979). However, sticky traps require almost daily attention to maintain the sticky surface and remove catches; hence, they were not satisfactory

---

Research entomologist at the Intermountain Forest and Range Experiment tion, Forest Service, U.S. Department of Agriculture, Ogden, Utah.

for use in this study. More recent barrier trap designs have replaced glass with plastics (Hines and Heikkenen 1977; Moeck 1980; Wilkening and others 1981; Younan and Hain 1982) or lightweight metal (Furniss 1981). Use of plastic for the barrier surface reduced overall trap weight. Even so, those trap designs were not usable for in-flight measures at three heights because their weight required they be suspended from a fixed support (Hines and Heikkenen 1977; Younan and Hain 1982). This support was attached to a sturdy branch on a live tree, and a person had to climb the tree and remove limbs beneath the branch chosen as the support. This system was unsuitable for the intended use of the traps because trees injured by limb removal would likely attract flying beetles, and the time required to hang such traps was prohibitive. Other traps have been modified to disperse synthetic pheromones (Moeck 1980; Furniss 1981; Lindgren 1983), but their configuration was not suited to intercepting bark beetles without these attractants. No traps, therefore, met all the requirements, especially those of weight and cost, imposed by the current study.

My design differs because it eliminates major metal components integral to other designs. This results in a lighter weight trap that permits three units to be suspended from the same nylon line using only tree limbs for support, but does not require that trees be climbed or branches removed to arrange support lines. Use of inexpensive, readily available plastic containers for collection and containment devices, rather than commercially available plastic or metal funnels, reduced unit cost to half that specified for traps of similar size and design (Wilkening and others 1981; Younan and Hain 1982). The trap has been used successfully since 1979 with only minor modification.

TRAP DESIGN

The trap consists of three components: (1) two Plexiglas panels positioned at right angles form the barrier surface (fig. 1A); (2) four funnellike collectors bolted to the base of the panels (fig. 1B); and (3) four plastic bottles to contain trapped insects attached to screw-type lids fitted to the base of the funnels (fig. 1C). The panel arrangement provides a maximum intercepting area above the funnels of 3.8 ft^2 (0.36 m^2). Insects strike the Plexiglas panels, cease flying, dropping into the funnels and then into the plastic bottles that are partially filled with water to prevent the beetles' escape. The bottles containing the catch are then unscrewed from the lids and emptied into a wire strainer to separate the insects from the water.

The assembled trap weighs 4 lb (1.8 kg), allowing it to be suspended within the forest canopy from lightweight nylon lines supported by tree limbs. This eliminates the need for towers or other supporting apparatus. The collecting component eliminates need for frequent tending, as is required with traps using motor-driven nets or sticky-type trapping surfaces that frequently must be cleaned of windblown debris. Additionally, this component retains the daily catch without the damage to specimens that normally results from prolonged co
finement. This facilitates identification. A 5 percent solution of sodium azide is added to the water in the collecting bottles to prevent growth of bacteria and mold when the interval between collections exceeds a week.

The design has several advantages over the conven
tional single barrier window trap. Untethered, the tra
serves as an omnidirectional barrier in contrast to the bidirectional barrier surface provided by the window trap. When tethered to prevent trap rotation, or affixe
to a stationary support, the trap—which has four ind
pendent collection and containment systems—could b
used to assess the direction of response of the insects caught.

Trap components are readily available, durable, co
venient to transport and store, require only periodic cleaning to maintain their effectiveness, and can be assembled without tools. Current cost of components for one trap is $11.50 (U.S.). Because panels are order
precut, the time required to fabricate the remaining components is one-half hour per trap.

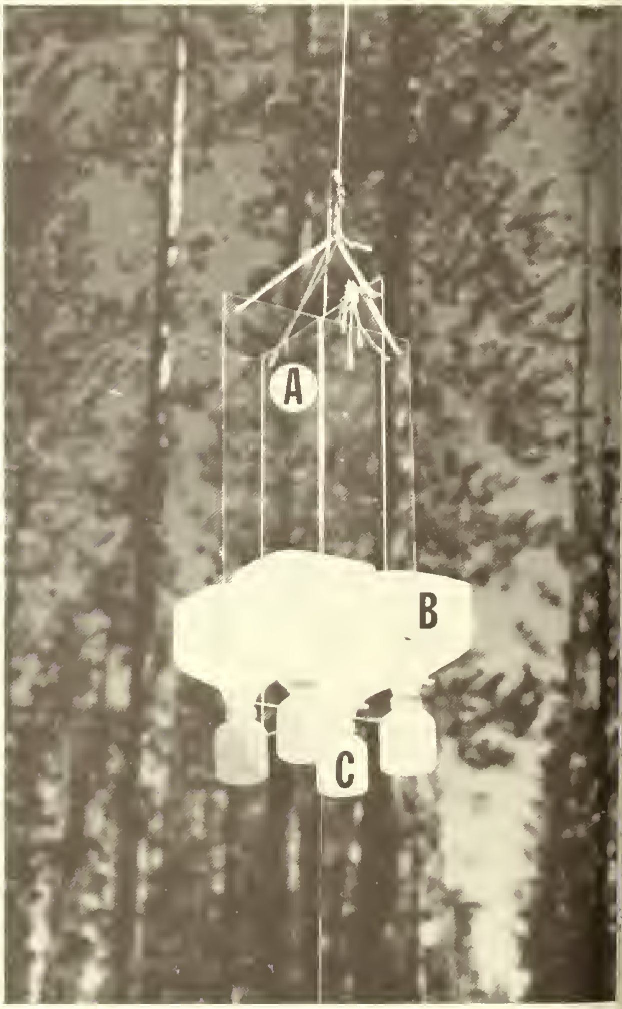
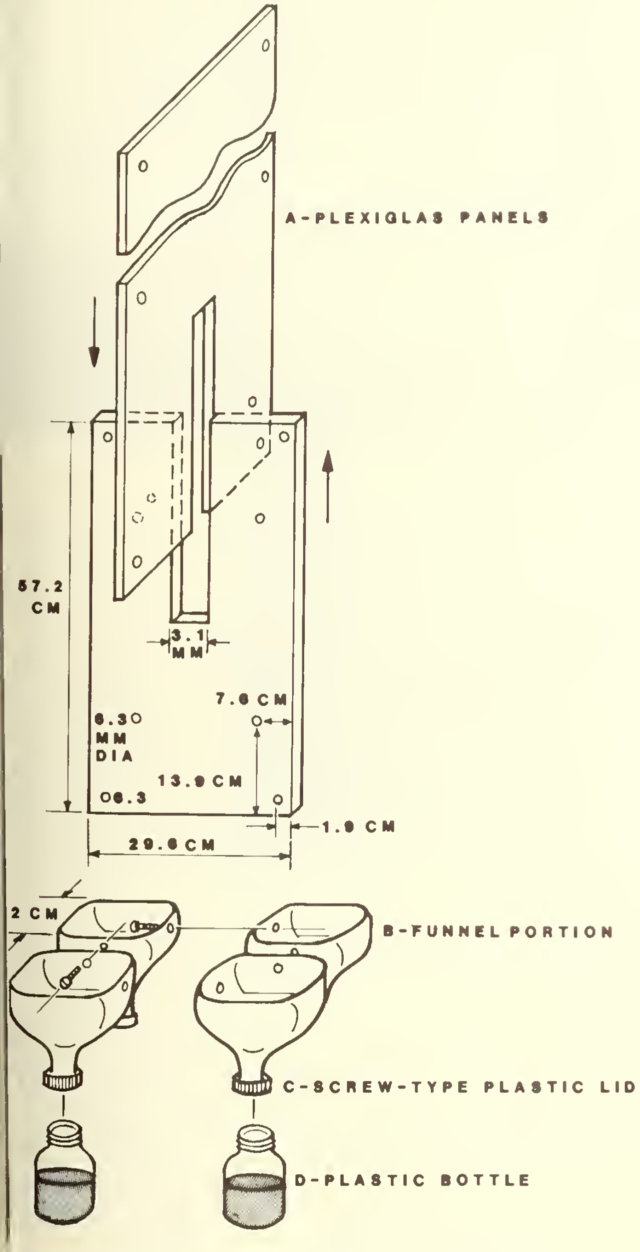


Figure 1.—Omnidirectional passive barrier trap consisting of (A) two Plexiglas panels positioned at right angles; (B) four funnellik collectors bolted to the base of the panels; (C) four plastic bottle to contain trapped insects.

CONSTRUCTION DETAIL

The barrier surface consists of two ⅛-inch-thick 3.1-mm) Plexiglas panels 11.75 inches wide by 22.5 inches high (29.8 by 57 cm) (fig. 2A). A slot ⅛ inch wide (3.1 mm), cut through the center of the ong dimension of each panel from the top to the mid-oint, allows two panels to be slipped together at right ngles. The panels are held in position by the top half f four 1-gal (4.5-liter) plastic milk containers 6 inches 15.2 cm) square fastened to them with four stove olts ⅝ inch by 7/32 inch in diameter (15.8 by .5 mm) (fig. 2B). The bolts are inserted through ¼-inch (6.3-mm) diameter holes positioned 3 inches 7.4 cm) from the outside edge and 5.5 inches (13.9 cm) from the bottom of each panel (fig. 2). By drilling these holes in both ends of each panel, the panels are interchangeable.



ure 2.—Schematic of construction details of omnidirectional sive barrier trap: (A) Plexiglas panels; (B) funnel portion; (C) ew-type plastic lid to attach collecting bottle to funnel; (D) stic bottle for containing trapped insects.

The neck of each funnel is fitted with a screw-type plastic lid to allow an 8-oz (0.28-liter) plastic bottle to be screwed onto the neck (fig. 2C, D). This bottle contains the trapped beetles. Four small holes, 1/32 inch (0.8 mm) diameter, punched in the sides of each bottle with a dissecting probe approximately 1.25 inch (3.1 cm) from the bottom, allow excess rain-water to drain from the bottles. Holes ¼ inch diameter (6.3 mm) drilled in the corners of each panel, ¾ inch (1.9 cm) from each edge, provide a means for attaching the 7/32-inch (5.5-mm) diameter nylon cord used to suspend the trap (fig. 2).

Funnels are cut from the top half of 1-gal plastic milk containers. Dimensions of the funnels are 6 inches square and 6 inches high, measured from the top edge of the side wall to the base of the neck. Approximately half the height of the lip at the apex of the bottleneck, which normally holds the snap lid in place, is removed to allow the collecting bottle to be screwed into its threaded cap far enough to hold it securely to the funnel (fig. 3A). Prior to attachment of the screw cap to the funnel, a hole 1.25 inch diameter is drilled through the center of the plastic screw lid [1.5 inch diameter (3.8 cm)] of the 8-oz collecting bottle so that it can be slipped over the funnel neck (fig. 3D). To facilitate attaching the lid, the neck of the funnel is scored with four 3/16-inch-wide (4.7-m) saw cuts, approximately 7/32 inch deep, spaced equidistant around the neck. The cuts permit the neck to momentarily be compressed to a smaller diameter to allow the inverted lid with a 1.25-inch diameter hole to slip over the neck of the funnel. When pressure is released, the funnel neck expands to its original diameter. This ensures that the lid fits tightly around the funnel neck above the lip, preventing the lid and attached bottle from slipping off the end of the funnel (fig. 3C). Holes in the collecting bottle lids are made with an adjustable hole saw. Plexiglas is cut with a table saw fitted with a blade for cutting plastics.

TRAP DEPLOYMENT

In use, three traps were tied to loops knotted in each vertical 7/32-inch (5.5-mm) diameter nylon line suspended over a pulley that was fastened to a horizontal support line of the same diameter (fig. 4A). Trees selected to support the horizontal line were chosen to ensure that the distance between adjoining edges of their crowns was at least 15 ft (4.6 m). This resulted in an opening of sufficient size to allow the vertical line supporting the traps to be positioned without becoming tangled in their branches.

The 7/32-inch diameter nylon horizontal support line was generally too long and heavy to position in the tree crowns without first shooting a lighter weight pilot line into position that could then be used to pull the nylon line into position. Consequently, a 15-lb (5.6-kg) test monofilament nylon line was first shot into position with a bow and arrow or Easy Liner line gun. A swivel

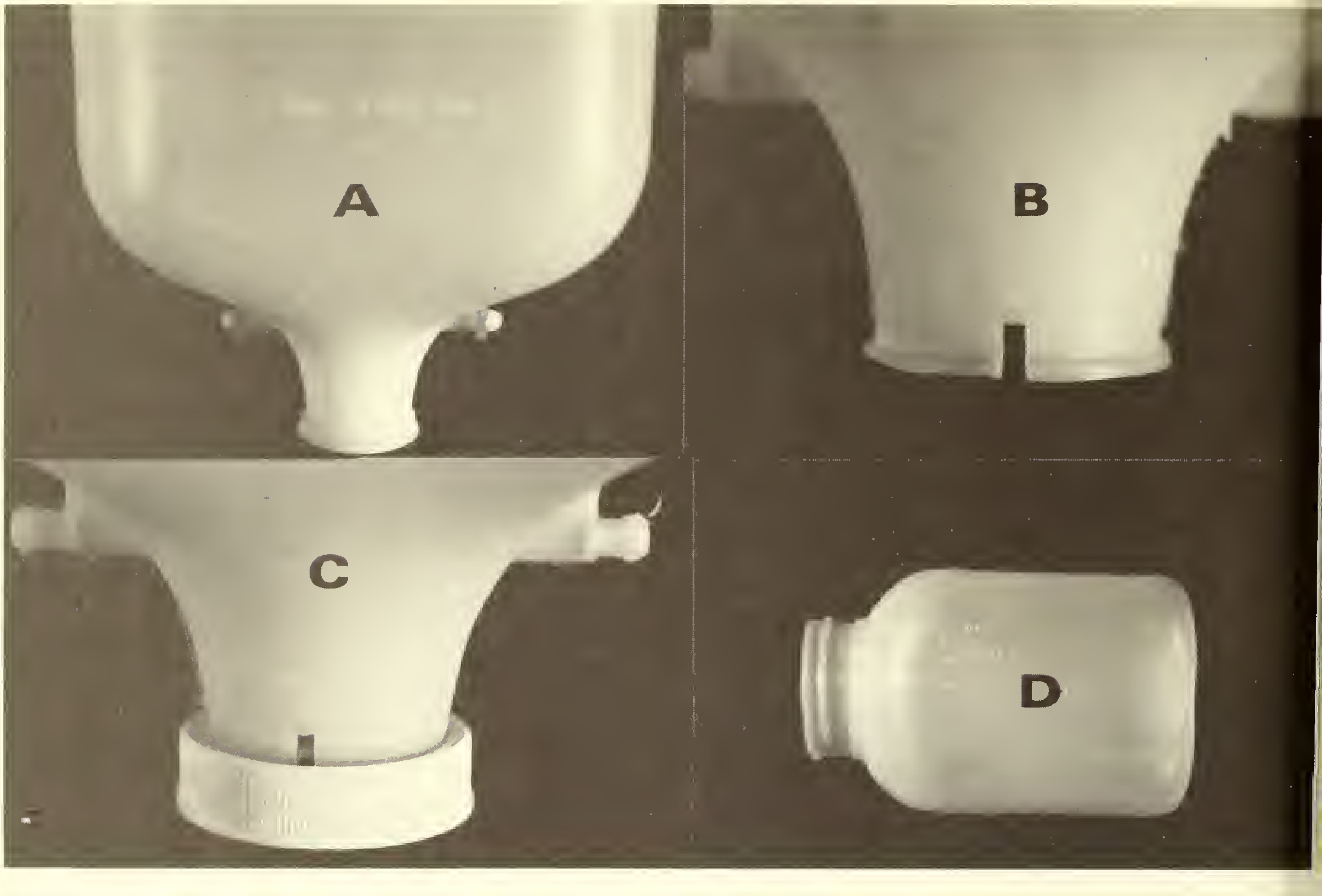


Figure 3.—Construction detail depicting method for attachment of lid of plastic collecting bottle to funnel: (A) top portion of plastic milk container (funnel) showing untrimmed container neck (arrow); (B) container showing neck with 3/16-inch-wide (2-mm) saw cuts (arrow) allowing neck to be compressed so that lid used to attach collecting bottle (D) can be slipped over funnel neck; (C) funnel with lid in place.

clip was tied to the end of the pilot line to simplify the task of attaching the arrow or line gun projectile and to allow them to spin in flight without twisting the line. The swivel was clipped to a loop of 20-lb (7.5-kg) test monofilament line threaded through a 1/16-inch (1.6-mm) diameter hole in front of the nock on the arrow shaft. The line gun projectile has a wire loop for attaching the swivel. The other end of the line was tied to a closed-face spinning reel, taped to the bow, to permit the line to be expelled and retrieved without tangling. The line gun employs a plastic projectile propelled by a .22-caliber rifle charge (industrial-type power load), in place of the arrow, and was better suited to placing lines when trees were taller than 90 ft (27.4 m).

Once the monofilament line was in place over or within the tree crowns, and the arrow or projectile with the monofilament line attached was on the ground, the 7/32-inch diameter nylon line was tied to the monofilament line and pulled back through the supporting tree crowns by winding the monofilament line on the spinning reel. A second line was then shot over the horizontal support line stretched across the opening between the crowns so that the support line could be pulled to the ground. A pulley was then attached and the vertical line supporting the traps was placed through the pulley. The two loose ends of the horizontal support line were then pulled taut and the pulley and vertical line positioned in the center of the opening between crowns. The two loose ends were then tied to the boles of the support trees to maintain tension.

Three traps were then tied to loops knotted in each vertical 7/32-inch diameter nylon line. The loops were positioned so that the topmost trap was located at mid-crown, midway between the extremities of the live crown; a second at midbole, midway between the ground and the bottom of the live crown; and the bottom trap 6 ft (1.8 m) above ground level. The end of the vertica line beneath the bottom trap was tied to a log on the ground to maintain placement of the vertical line. Once in position, the traps were maintained at the proper height by tying the opposite end of the vertical line to a nearby tree.

Figure 4.—Deployment of omnidirectional passive barrier trap: (A) horizontal support line with pulley for attachment of vertical line; (B) vertical line used to raise and lower traps, with tree traps attached.

TEST LOCATION AND DURATION

To evaluate the traps' effectiveness for determining the relative abundance of bark beetles, 120 traps were hung in 10 mature lodgepole pine stands infested by outbreak population levels of the mountain pine beetle. The 10 stands were on three National Forests in western Montana, including the Kootenai National Forest near Libby, the Lolo National Forest near Thompson Falls, and the Gallatin National Forest near West Yellowstone. Trapping was conducted during the seasonal flight of the mountain pine beetle. The onset and termination of seasonal flight varied by site, but was within the period July 2 to August 22, 1980. The number of traps deployed and the duration of flight at each site resulted in 2,502 trap days.

EVALUATION OF TRAP CATCH

Scolytidae

Effectiveness of this trap for assessing the relative abundance of in-flight populations of bark beetles was evaluated by comparing the proportion of scolytids trapped to other taxa of insects with the proportions caught during evaluations of the other passive barrier-type traps referenced earlier. A total of 8,757 insects were caught by the 120 traps between July 2 and August 28, 1980, at the 10 study sites (table 1). Of all the orders trapped, Coleoptera were caught most frequently: 49 percent of the total (table 1). Within this order, Scolytidae was the single most abundant family trapped, 37 percent of all the Coleoptera and including eight genera other than *Dendroctonus*. Three families of beetles that commonly inhabit trees infested with bark beetles ("scolytid associates") totaled 22 percent of the coleopterans caught, while the remaining 40 percent were divided among 11 families, with Mordellidae being the most abundant.

Limiting comparison to the proportion Scolytidae represent of all Coleoptera caught, the 37 percent caught with my trap is similar to the 39 percent recorded by Hosking (1979) using window traps in a ponderosa pine stand (*Pinus ponderosa* Laws.) in New Zealand. The baffled barrier trap used by Younan and Hain (1982) in southern pine forests was superior to four other designs for trapping Coleoptera and Scolytidae. Scolytids constituted 67 percent of the Coleoptera caught by this trap. The higher percentage of scolytids caught with the baffled barrier trap is probably due to their placement in trees that had been completely severed at the root collar, making them especially attractive to scolytids. Chapman and Kinghorn (1955) used a window trap to sample flying populations of the ambrosia beetle *Trypodendron* sp. (Coleoptera: Scolytidae). They found that of 1,241 insects caught over 3 days, Scolytidae were most abundant, while other Coleoptera were the next most numerous. Hosking (1979) also determined the window trap caught more scolytids than any other family of Coleoptera. In contrast, Juillet (1963) found his glass barrier trap most effective for intercepting Diptera, although Coleoptera were the next most abundant. The fact scolytids were also the predominant insect family caught by my trap demonstrates that the design was as effective as other barrier trap designs for determining the relative abundance of this group of insects (table 2).

The need to hang traps at more than one stratum to determine relative abundance, particularly at low population levels, was verified by comparing the total catch at the three trapping heights (table 3). Most mountain pine beetles were caught at midbole (56 percent), followed by midcrown (34 percent), and the bottom position (10 percent). These results confirmed findings of an earlier study that revealed midbole traps caught the highest percentage (48 percent) of the 422 beetles trapped (Schmitz and others 1981). However, the same study found that the second highest percentage (28 percent) was caught by the lowest traps rather than midcrown, as was the case in this study. A more detailed analysis of the microenvironment of the stands involved is needed to determine the reasons for these differences.

Associated Insect Orders

The trap intercepted insects other than scolytids. The variety and abundance of insects caught during 1980 are shown in table 1. Relative abundance of insects by order was Coleoptera 49 percent, Hemiptera 14 percent, Diptera 14 percent, and Hymenoptera 8 percent. Comparison of the abundance of insects other than scolytids revealed my trap design and those barrier trap designs referenced earlier were more effective for catching Coleoptera than any other order (table 2). Hemiptera was the third most abundant taxa and the second most abundant order caught by my trap, while it was the fourth most frequently caught taxa by three designs for which the catch of insects other than Coleoptera was reported. I found Diptera to be the next most abundant (table 1), but my ranking differed from that reported for the other three designs (table 2). Variation in the number of Diptera caught by the five designs was greater than for any other order. Hymenoptera was the fifth most abundant order caught by my trap. Two of the other designs caught Hymenoptera more frequently, ranking it the third most taxa caught (table 2). Some variation in the relative abundance of these associated orders is attributable to the broad range in forest types in which the different designs were used and to the timing of the tests. Aside from the exceptions noted, the overall similarity in abundance of these insect orders suggests my trap will provide a measure of their relative abundance equal to that provided by the other barrier trap designs included in the comparison.

The trap intercepted several families of beetles normally associated with bark beetle infestations, including the predacious checkered beetles (Coleoptera: Cleridae). Not unexpectedly, the trap caught fewer of the small-bodied, lightweight associates such as the predacious flies (Diptera: Dolochopodidae) and parasitoids (Hymenoptera: Braconidae). These insects continue flying upon striking the barrier surface, gradually moving upward away from the funnels, in contrast to beetles that upon impact stop flying and drop into the funnels. These results are similar to those obtained by Younan

Table 1.—Number and percent of insects caught by 120 passive barrier traps at 10 study sites on three locations in Montana, combined, July 2 to August 28, 1980[1]

Order	Number caught		Percent of catch		Percent of Coleoptera caught
Coleoptera (combined)		4,302		49.1	
Scolytidae:					
Pityogenes spp.	512		6.0		
Dendroctonus ponderosa	391		4.0		
Pityophthorus spp.	321		4.0		
Scolytus spp.	193		2.0		
Ips spp.	166		1.9		
Trypodendron spp.	18		.2		
Hylastes spp.	8		.1		
Carphoborus spp.	3		.1		
Dryocetes spp.	3		.1		
Total:	1,615		18.5		37.6
Scolytid Associates:					
Cerambycidae	743				
Cleridae	136				
Buprestidae	81				
Total:	960		10.9		22.3
Other Coleoptera:	1,727		19.7		40.1
Hemiptera		1,286		14.7	
Diptera		1,271		14.5	
Hymenoptera		730		8.3	
Lepidoptera		683		7.8	
Homoptera		352		4.0	
Neuroptera		97		1.1	
Orthoptera		12		.1	
Ephemeroptera		3		.1	
Trichoptera		3		.1	
TOTAL		8,757		100.0	100.0

[1]The number of traps deployed and the seasonal flight period at each of the three Forests, combined, resulted in 2,502 trap days.

Table 2.—Ranking by number of specimens caught for five taxa of insects intercepted by five passive-type barrier trap designs[1]

Trap design	Coleoptera	Scolytidae	Hemiptera	Diptera	Hymenoptera
Test trap	1	2	3	4	5
Chapman 1955	1	2	4	3	5
Hosking 1979	1	2	—	—	—
uillet 1963	1	—	4	1	3
Younan and Hain 1982	1	2	4	5	3

[1]1 = most abundant; 5 least abundant.

able 3.—Number and percentage of mountain pine beetles caught by 120 passive barrier traps by height and trapping location, July 2 to August 28, 1980[1]

rapping cation	Trap height						
	Bottom		Midbole		Midcrown		Total
	No.	*Percent*	*No.*	*Percent*	*No.*	*Percent*	
allatin NF	12	26	23	50	11	24	46
ootenai NF	18	6	164	56	111	38	293
olo NF	10	19	33	64	9	17	52
Total	40	10	220	56	131	34	391

[1]The number of traps deployed and the seasonal flight period at each of the three Forests, combined, resulted in 2,502 trap days.

and Hain (1982), who found that although Hymenoptera were the second most abundant group of insects caught by their baffled barrier trap, the design was the least efficient of five designs tested for intercepting Diptera and Hymenoptera.

APPLICATION

The trap and suspension system are best suited for determining the relative abundance of Coleoptera at several heights within the canopy as might be required by pre- and posttreatment measures of population density. The traps have also been used to determine the seasonal abundance, dispersion, and flight habits of a number of scolytids associated with the mountain pine beetle. Such information is needed to determine their role in the population dynamics of the mountain pine beetle. These data are also needed to plan the timing of cutting, especially thinning, to prevent population increases of those associated scolytid species that infest fresh thinning slash and then emerge to kill crop trees in the residual stand.

SUMMARY

The modified passive barrier trap design is effective for determining relative abundance and vertical distribution of in-flight populations of bark beetles in lodgepole pine stands. The design is also effective for intercepting other insects, particularly Coleoptera. The trap weighs less than other traps of similar size and design, and that allows traps to be suspended in the upper canopy using only limbs for support. This feature permits measures of relative population density within the canopy that heretofore were unobtainable without a more elaborate support system. The passive design offers an alternative to sampling systems that require synthetic attractants for censusing in-flight populations. Synthetic attractants artificially concentrate flying populations, making it difficult to relate the catch to natural unit area densities because dispersion characteristics of the attractant and the threshold of response of the target beetles are seldom known. Additionally, the comparatively low unit cost ($11.50 U.S.) allows for placement of a greater number of traps for the same cost as more expensive designs currently in use. The system has been used for 5 years without need for modification to obtain the desired measures of relative abundance.

ACKNOWLEDGMENTS

I thank Lynn A. Rasmussen, biological technician at the Intermountain Forest and Range Experiment Station, Ogden, Utah, for his contribution to improving fabrication methods and reducing the time required to assemble a trap.

REFERENCES

Avis, R. W. Flight and attack patterns. The mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Coleoptera: Scolytidae). Vancouver, BC: University of British Columbia; 1971. 58 p. M.S. thesis.

Chapman, J. A.; Kinghorn, J. M. Window flight traps for insects. Canadian Entomologist. 87: 46-47; 1955.

Furniss, M. M. An improved nonsticky trap for field testing Scolytid pheromones. Environmental Entomology. 10: 161-163; 1981.

Hines, J. W.; Heikkenen, H. J. Beetles attracted to severed Virginia pine (*Pinus virginiana* Mill.). Environmental Entomology. 6: 123-127; 1977.

Hosking, G. P. Trap comparison in capture of flying Coleoptera. New Zealand Entomology. 7: 87-92; 1979.

Hosking, G. P.; Knight, F. B. Investigations of the life history and habits of *Pityokteines sparsus* (Coleoptera: Scolytidae). Technical Bulletin 81. Orono, ME: University of Maine, Life Sciences and Agriculture Experiment Station; 1976. 37 p.

Hosking, G. P.; Knight, F. B. Flight habits of some Scolytidae in the spruce-fir type of northern Maine. Annals Entomological Society of America. 68: 917-921; 1975.

Juillet, J. A. A comparison of four types of traps used for capturing flying insects. Canadian Journal of Zoology. 41: 219-223; 1963.

Lindgren, B. S. A multiple funnel trap for scolytid beetles (Coleoptera). Canadian Entomologist. 115: 299-302; 1983.

Moeck, H. A. Field test of Swedish "drain pipe" pheromone trap with mountain pine beetle. Canadian Forest Service Bimonthly Research Notes. 36(1): 2-3; 1980.

Schmitz, R. F.; McGregor, M. D.; Amman, G. D. Mountain pine beetle response to lodgepole pine stands of different characteristics. In: Berryman, A. A.; Safranyik, L., eds. Dispersal of forest insects: evaluation, theory, and management implications: proceedings of the second IUFRO conference; 1979 August 27-31; Sandpoint, ID. Pullman, WA: Washington State University, Cooperative Extension Service; 1980: 234-243.

Wilkening, A. J.; Foltz, J. L.; Atkinson, T. H.; Connor M. D. An omnidirectional flight trap for ascending and descending insects. Canadian Entomologist. 113 453-455; 1981.

Younan, E. G.; Hain, F. P. Evaluation of five trap designs for sampling insects associated with severed pines. Canadian Entomologist. 114: 789-796; 1982.

U.S. GOVERNMENT PRINTING OFFICE: 1984—776-032/10512 REGION NO. 8

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Note
INT-349

January 1985

Susceptibility of Lodgepole Pine to the Needle Cast Fungus *Lophodermella concolor*

Ray J. Hoff

Susceptibility of Lodgepole Pine to the Needle Cast Fungus *Lophodermella concolor*

Ray J. Hoff[1]

ABSTRACT

Needle cast caused by Lophodermella concolor *is a common disease of lodgepole pine when wet springs and early summers occur. Variability of infection among 30 stands was highly significant. The correlation for elevation of stand versus degree of infection was 0.82. Family heritability was 0.71 (191 families), and* h^2 *based on individuals was 0.33.*

KEYWORDS: needle cast, *Lophodermella concolor*, lodgepole pine

A common needle disease of lodgepole pine (*Pinus contorta* Dougl.) in the Northern Rocky Mountains is a needle cast caused by *Lophodermella concolor* (Dearn.) Darker. Spores from infected 1-year-old needles infect the newly emerging needles of the current year. The disease is not obvious until the next spring and early summmer when the needles turn brown to reddish brown. Infection is observed most frequently on young seedlings in moist, cool valleys (Krebill 1975).

The wetter and generally cooler conditions that have prevailed in the Northern Rockies over the last several years have increased the incidence of this disease. Although the impact of this needle cast has not been assessed, it is generally expected to decrease growth, especially if there are successive years of infection. For example, 6 successive years of infection by a closely related species, *Lophodermella sulcigena* (Rostr.) v. Höhn. on Corsican pine (*Pinus nigra* var. *maritinea* [Acton] Melville), resulted in a 59 percent reduction in volume growth (Mitchell and others 1976).

Mitchell and others (1976) pointed out that normally not all trees are infected in a stand; resistance in Corsican pine to *L. sulcigena* appears to be fairly common. Wagener (1959) and Staley and Bynum (1972) also report the incidence of resistant *Pinus ponderosa* Laws. trees to *Lophodermella morbida*.

The Inland Empire Tree Improvement Cooperative has established 20 plantations of lodgepole pine. One of these tests was established by the Forest Service at a site in northern Idaho that exhibited heavy needle cast infection in 1983. Although the infection appeared uniformly heavy over the entire plantation, there were many scattered individuals here and there that either were not infected or on which the infection was very light. The purpose of this paper is to assess the susceptibility of lodgepole pine to needle cast as related to source of seed and family.

MATERIALS AND METHODS

The provenance-progeny test plantation was planted during spring 1980 at the Lone Mountain Tree Improvement Center located 25 miles (40 km) north of Coeur d'Alene, ID. The site is flat with only slight undulations at an elevation of 2,488 ft (758 m). The entire 160-acre (65-ha) site is surrounded by naturally regenerated lodgepole pine and ponderosa pine with a lesser mixture of grand fir, Douglas-fir, and western larch. This natural stand is two-layered with the overstory composed of mature or overmature scattered trees (remnants of harvest) while the lower layer is a pole-sized stand 20 to 30 ft (6 to 9 m) tall. Most of the lodgepole pine and many of the ponderosa pine trees were infected to some degree by needle cast.

The lodgepole pine plantation is situated in the southwest corner of the tree improvement site. The rectangular plantation measures 600 by 1,500 ft (183 by 457 m), and two sides are 20 ft (6 m) from the natural stand.

The seed came from 191 open pollinated individual trees (families) from 30 localities (stands) throughout northern Idaho. The stands and number of families represented in each stand are listed in table 1.

The seedlings were grown at the Forest Service nursery at Coeur d'Alene in 4-in^3 (66-cm^3) plastic containers and planted at the Lone Mountain plantation site in March 1980 just prior to their second growing season. The experimental design used was a randomized complete block with five replications (blocks). Eight progeny of each family were planted per replication as single-tree plots.

---

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

Table 1.—Stand descriptions and number of families per stand of lodgepole pine planted at Lone Mountain

Stands	Families	Latitude		Longitude		Elevation		Miles from Lone Mountain
		Degrees	*Min*	*Degrees*	*Min*	*Feet*	*(Meters)*	
101	2	48	59	118	00	3,700	(1 100)	95
102	10	48	41	118	30	4,500	(1 400)	100
104	13	48	27	116	53	2,500	(800)	35
105	7	48	27	117	11	3,900	(1 200)	47
108	5	48	06	116	16	3,500	(1 100)	33
110	5	48	05	116	12	5,100	(1 600)	33
112	2	47	49	116	29	4,000	(1 200)	8
113	5	47	49	116	29	4,000	(1 200)	10
114	3	47	48	116	44	2,800	(900)	3
115	4	47	48	116	15	4,500	(1 400)	25
116	10	47	48	116	14	5,000	(1 500)	27
117	7	47	15	116	32	4,500	(1 400)	42
119	7	47	11	116	51	4,500	(1 400)	48
120	6	47	12	116	50	4,300	(1 300)	50
123	2	47	01	116	20	3,000	(900)	60
124	9	46	56	116	37	3,800	(1 200)	65
125	10	46	53	115	08	5,500	(1 700)	102
126	9	46	50	116	30	2,800	(900)	77
127	10	46	41	115	36	4,300	(1 300)	103
128	9	46	40	114	59	6,000	(1 800)	123
129	8	46	38	114	32	5,600	(1 700)	148
130	3	46	38	114	34	5,200	(1 600)	145
131	10	46	37	114	42	5,000	(1 500)	140
132	2	46	36	115	37	3,800	(1 200)	12
134	6	46	34	115	52	3,300	(1 000)	107
135	2	45	51	115	24	4,500	(1 400)	153
139	10	45	45	115	56	4,600	(1 400)	157
140	5	45	42	116	01	5,800	(1 800)	160
141	5	46	08	116	41	4,000	(1 200)	122
155	5	47	09	116	52	5,000	(1 500)	52

Data were taken when the maximum expression of disease symptoms was evident; this occurred mid-June in the middle of the trees' fourth growing season. The plantation was first examined for 20 to 30 minutes to get a feel for general level and range of infection. The infection levels were noted by slowly walking along a row of seedlings. Five infection categories were then selected (fig. 1), all involving 1-year-old needles:

0 = no needle tissue was infected
1 = less than 5 percent of needle tissue was infected
2 = from 6 to 36 percent
3 = from 37 to 69 percent
4 = more than 70 percent

Prior to analysis, the five categories were changed to the mean proportion for each class—that is: 1 = 0.025; 2 = 0.21; 3 = 0.53; 4 = 0.85. For computing purposes, 0 = 0.0004.

The analysis of variance and expected mean squares are shown in table 2. The design was unbalanced for both families within stands and individuals within families requiring a combination of Anova and GLM (SAS 1979) to derive the data. However, because of the size of the test, the deviations for the individual within family-stand-block were derived separately for each plot and then divided by the harmonic mean of individuals.

Regressions of stands on elevation, latitude, longitude, and habitat type were derived with the 1979 statistical analysis system (SAS).

Table 2.—Model for analysis of variance and expected mean squares

Source of variation	d.f.	Expected mean square[1]
Block	4	$\sigma^2_W + p\sigma^2_E$ $+pf\sigma^2_E$
Stand	29	$\sigma^2_W + p\sigma^2_E + pb\sigma^2_{F/S} + pf^*b\sigma^2_S$
Family in stand	161	$\sigma^2_W + p\sigma^2_E + pb\sigma^2_{F/S}$
Experimental error[2]	760	$\sigma^2_W + p\sigma^2_E$
Within plot	5,004	σ^2_W

[1] Where: b = 5, S = 30, f = 191, f* = 4.60 harmonic mean of families in stands, p = 5.75 harmonic mean of individuals within plots-families-blocks.

[2] Contains all sources of variance involving interaction of blocks.

Figure 1.—Examples of degrees of infection of needle rust on lodgepole pine. A = no infection, B = light infection (2 on my scheme) – not to be confused with white cottony material caused by woolly aphid, C = moderate infection (3 on my scheme), D = heavy infection (4 on my scheme).

Heritability was calculated using the following formulas:

For individual

$$h_I^2 = \frac{4\sigma^2_{F/S}}{\sigma^2_{F/S} + \sigma^2_W}$$

For family

$$h_F^2 = \frac{\sigma^2_{F/S}}{\sigma^2_{F/S} + \frac{\sigma^2_W}{pb} + \frac{\sigma^2_E}{b}}$$

where $4\sigma^2_{F/S}$ is the estimated additive variance for individuals and $\sigma^2_{F/S}$ for families.

RESULTS

The level of damage by needle cast varied from no damage (6.2 percent of the trees) to almost complete defoliation (4.9 percent of the trees). The amount of damage is summarized in table 3, and examples of the visual classes are shown in figure 1.

Analysis of variance of the percentage of trees in each category of foliage damaged is shown in table 4. Stands and families in stands were highly significant. Variance components are shown in table 5. Heritability based on individuals was 0.331; for families 0.710.

The associations (r^2) of needle cast damage with latitude, longitude, elevation, and distance from Lone Mountain were 0.03, 0.07, 0.63, and 0.25, respectively.

Table 3.—The level of damage by needle cast on year-old foliage of lodgepole pine by category used in visual rating

	Amount of foliage damaged		Trees	
Category	Mean	Range		
	-----*Percent*-----		*No.*	*Percent*
0	0	0	374	6.2
1	2.5	>5	1,103	18.3
2	21.0	6-36	2,280	37.9
3	53.0	37-69	1,962	32.6
4	85.0	>70	292	4.9

Table 4.—Analysis of variance of damage by needle cast on lodgepole pine

Source of variance	d.f.	SS	MS	F
Block	4	2.1694	0.5424	
Stand	29	9.3738	.3232	13.58**
Family in stand	161	3.8306	.0238	3.55**
Experimental error	760	5.1012	.0067	
Within family	5,004	32.7096	.0065	

**Significant at the 1 percent level of probability.

Table 5.—Variance components and harmonic means

Component		Variance
Stand	σ^2_S	0.0023
Family in stand	$\sigma^2_{F/S}$	.00059
Experimental error	σ^2_E	.00003
Within family	σ^2_W	.0065
Harmonic means:		
Family in stands	f*	4.60
Individuals in families	p	5.75

DISCUSSION

The most striking geographic pattern of variation was that associated with increase in susceptibility with increasing elevation (fig. 2). This is likely related to the phenological differences of lodgepole pine at various elevations together with requirements for successful nfection by the needle cast fungus.

Bud break is later, duration of growth is shorter, and bud set is earlier with increasing elevation (Rehfeldt and Wykoff 1981). At 5,000 ft (1 500 m) buds burst about the first week of June in northern Idaho, and by that time or shortly after, weather conditions change from a typical high-humidity, rainy period to warmer and drier. This effectively prevents infecting by the fungus. Meanwhile, at low elevation, which is from 2,100 ft (640 m) in northern Idaho, growth starts about the first week of April and continues throughout the wet period. Thus, the stands with highest resistance were found in those ocalities where the fungus and the host coexist most frequently—that is, at low elevations.

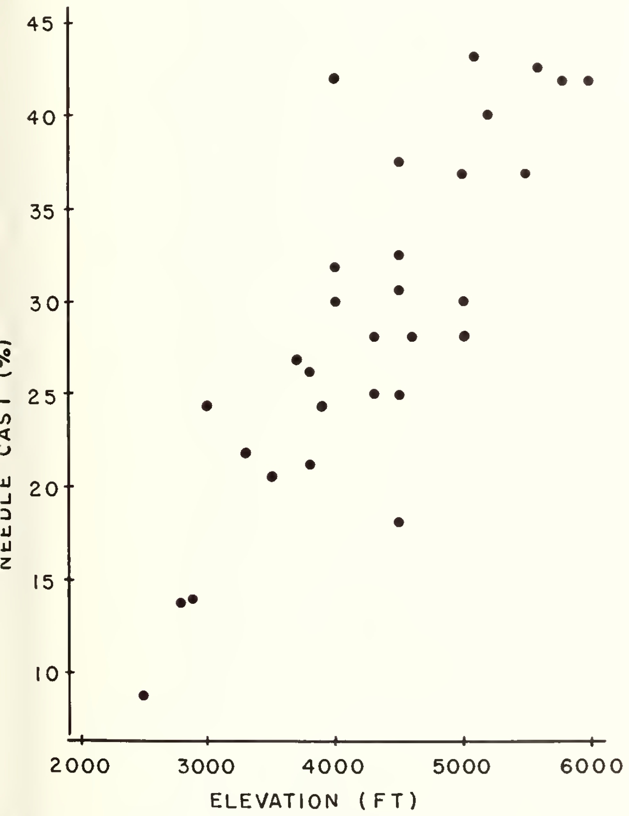


Figure 2.—Scatter diagram of average needle cast per stand over elevations of stand in thousands of feet.

The wet spring-early summer conditions are frequently interspersed with a week or two of dry weather, causing variation in disease severity over years. In the last 5 to 10 years weather conditions have become more uniformly and consistently wet, resulting in more frequent and more severe needle diseases in general on several tree species.

Infection of natural lodgepole pine and ponderosa pine surrounding the lodgepole pine test cited in this paper was quite high, which shows that resistance is not 100 percent even at this low elevation. This lack of fixation of resistant genes is likely the result of the variation in weather conditions over years and especially within the long-term, relatively drier conditions that prevailed over much of the Inland Northwest from the 1920's through the 1960's. If the present trend is maintained, one would expect an increase in selection pressure for resistance.

Rehfeldt (1980a,b) has emphasized the need to delineate adaptive variation. Each tree species has become adapted to its environment according to the genetic patterns or requirements within its genetic system. Pest problems, as well as the more obvious environmental factors (temperature, soil moisture, and so forth) are also part of the selection forces acting on the svstems.

Most pests are problems only in certain areas or during certain years; for example, needle cast is probably no problem in the management of lodgepole pine at elevations above 3,500 to 4,000 ft (1 067 to 1 219 m) for any year and below that for most years. And yet forest managers should probably limit seed transfer to forestall maladaptations to needle cast. Transfer of seed to a higher elevation would presumably decrease the risk of damage by needle cast. On the other hand, the risk of cold damage increases.

Individual and family heritabilities were quite high and, consequently, genetic gains in resistance could be substantial. However, pest problems come and go depending on favorable environmental conditions. Therefore, it isn't always necessary or even desirable (because it can needlessly decrease the gene pool) to breed for resistance just because there is a disease problem for a few years. What is important is to make sure that resistance levels are not decreased and that they are attuned to environmental conditions. But if the trend is for wet weather for the future, then resistance breeding may be necessary to offset growth impact of the disease.

This study is another example of how our forest species are well tuned to their environments and why movement of seed sources should be done carefully. It also shows that resistance of individuals and families should be maintained or enhanced to match changes in the environment.

REFERENCES

Krebill, R. G. Lodgepole pine's fungus-caused diseases and decays. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: proceedings. Vol. 1. Pullman, WA: Washington State University; 1975: 377-405.

Mitchell, C. P.; Millar, C. S.; Haworth, M. N. Effect of the needle-cast fungus *Lophodermella sulcigena* on growth of Corsican pine. Forestry. 49(2): 153-158; 1976.

Rehfeldt, G. E. Cold hardiness of western larch populations. Research Note INT-288. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980a. 3 p.

Rehfeldt, G. E. Cold acclimation in populations of *Pinus contorta* from the Northern Rocky Mountains. Botanical Gazette. 141(4): 458-463; 1980b.

Rehfeldt, G. E.; Wykoff, W. R. Periodicity in shoot elongation among populations of *Pinus contorta* from the Northern Rocky Mountains. Annals of Botany. 48: 371-377; 1981.

SAS Institute, Inc. SAS user's guide: statistics. Cary, NC: SAS Institute, Inc.; 1979. 494 p.

Staley, J. M.; Bynum, H. H. A new *Lophodermella* on *Pinus ponderosa* and *P. attenuata*. Mycologia. 64: 722-726; 1972.

Wagener, Willis W. The effect of a western needle fungus (*Hypodermella medusa* Dearn.) on pines and its significance in forest management. Journal of Forestry. 57: 561-564; 1959.

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

ited States
epartment of
riculture

rest Service

ermountain
rest and Range
periment Station
gden, UT 84401

esearch Note
T-350

arch 1985

Response of Broom Snakeweed to Application of Tebuthiuron

Warren P. Clary
Sherel Goodrich
Benton M. Smith

ACKNOWLEDGMENT

Authors acknowledge Richard Bjerregaard, representative of Eli Lilly and Company, for his assistance and for materials furnished for this study.

Response of Broom Snakeweed to Application of Tebuthiuron

Warren P. Clary
Sherel Goodrich
Benton M. Smith[1]

BSTRACT

Application of pelleted tebuthiuron initially reduced mbers of broom snakeweed plants and suppressed elds of Fairway wheatgrass. Effects of herbicide sidues in reducing broom snakeweed plants were still served after 4 years. However, erratic control and ease plant reestablishment suggests that tebuthiuron is not effective control of broom snakeweed in the Interountain area.

EYWORDS: tebuthiuron, herbicide, broom snakeweed, *Xanthocephalum sarothrae*

Broom snakeweed (*Xanthocephalum sarothrae* [Pursh] hinners) is a common half-shrub in the Western United tates. It is a short-lived perennial that often aggresvely increases in disturbed areas. However, its populaons are cyclic and are therefore not reliable indicators overgrazing (Jameson 1970).

Broom snakeweed can strongly suppress production of arm-season short grasses (Jameson 1966; Ueckert 1979) nd may be toxic to livestock (Sperry and others 1964). ossibly the only positive attribute is its value as a food em for such wildlife as scaled quail (*Callipepla uamata*) (Davis and others 1975) and pronghorn *ntilocapra americana*) (Couey 1946; Smith and Beale 980).

The control of broom snakeweed with herbicides has een erratic. However, a number of chemicals have been ffective (Johnsen 1966; Sosebee and others 1982). ebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl] N,N'-dimethylurea)—applied as a wettable powder at .5 lb/acre (0.6 kg/ha) active ingredient (a.i.) or in elleted form at 0.45 lb/acre (0.5 kg/ha) a.i.—controlled room snakeweed in Texas (Sosebee and others 1979; acoby and others 1982). Also, 2 lb/acre (2.2 kg/ha) or ore of pelleted tebuthiuron has controlled broom snakeeed in Wyoming and Arizona (Alley and Humburg 978; Johnsen and Madrigal 1979).

This study was undertaken to evaluate the effectiveess of pelleted tebuthiuron in controlling broom snakeeed on a central Utah site.

METHODS

The test site is in the northeastern portion of Millard County, UT, on the Church Hills area of the Fishlake National Forest. Annual precipitation on the study area averages 14 inches (36 cm). Precipitation falls predominantly in the cool portion of the year. The months of June through September each average less than 1 inch (2.5 cm) of rainfall. Weather records from nearby communities of Oak City and Scipio show that the 4 years after herbicide application (fall 1979) were wetter than usual. Water year 1980 (October through September) was 54 percent above the long-term mean, 1981 was 1 percent above the mean, 1982 was 62 percent above the mean, and 1983 was 57 percent above the mean. Surface soil is a gravelly, very fine sandy loam developed on short alluvial fans originating from the south end of the Canyon Mountains. Quartzite and some limestone are the parent rocks.

At the time of the study, the predominant plants on the study site were Fairway wheatgrass (*Agropyron cristatum* [L.] Gaertn.), cheatgrass brome (*Bromus tectorum* L.), bulbous bluegrass (*Poa bulbosa* L.), bur buttercup (*Ranunculus testiculatus* Crantz), mountain big sagebrush (*Artemisia tridentata vaseyana* [Rydb.] Beetle), and broom snakeweed.

Tebuthiuron pellets were applied aerially (October 1979) on randomly selected parallel strips 168 feet (51 m) wide, perpendicularly across three gently sloping ridgetops containing the broom snakeweed communities. Application rates of 10 percent a.i. pellets were 0, 0.6, 0.9, and 1.2 lb/acre (0, 0.6, 1.0, and 1.3 kg/ha) a.i., which resulted in 1.1, 1.6, and 2.2 pellets per square foot of soil surface (12, 17, and 24 pellets per square meter) (Elanco 1983). The rates were each replicated two times for a total of eight strips. A randomized block experimental design was used. Each strip was sampled by two clusters of four 108-ft^2 (10-m^2) permanent circular plots, wherein counts of live broom snakeweed plants were made. Herbage production was determined on 9.6-ft^2 (0.9-m^2) plots centered within each of the 108-ft^2 plots by estimating wet weight. Herbage on every fifth plot was clipped, ovendried, and weighed as a basis for calculating dry weight from wet weight.

Vegetation evaluations were conducted in the growing seasons of 1980, 1981, 1982, and 1983. All observations and measurements were completed by midsummer each year.

---

[1] Authors are supervisory range scientist, Forestry Sciences Laborary, Intermountain Forest and Range Experiment Station, USDA rest Service, Boise, ID; range conservationist, Vernal Ranger strict, Ashley National Forest, USDA Forest Service, Vernal, UT; and nge conservationist, Fillmore Ranger District, Fishlake National rest, USDA Forest Service, Fillmore, UT.

RESULTS AND DISCUSSION

Two after-application results were monitored. One was the degree of control of broom snakeweed. The other was the subsequent response of other plants.

Control of Broom Snakeweed

Control of broom snakeweed by pelleted tebuthiuron was erratic (table 1). The first growing season after application, the two heaviest rates (0.9 and 1.2 lb/acre) significantly reduced the number of snakeweed plants and a nonsignificant reduction appeared to occur under the lightest rate. However, the second year a large increase in plants occurred due to establishment of new seedlings in all strips including strips with no herbicide.

Table 1.—Number of broom snakeweed plants per 108 ft^2 by year and tebuthiuron application rate

	Active ingredient (lb/acre)			
Year	0	0.6	0.9	1.2
1980	22a[1]	12ab	8b	8b
1981	139a	345a	106a	148a
1982	167a	160a	62a	62a
1983	73a	37ab	12b	16b

[1] Values followed by different letters within years are significantly different at $P<0.05$.

Although there were no significant differences in plant numbers, the largest apparent increase occurred in the strips with the light application rate. Presumably, this was a result of a combination of reduction in plant competition due to herbicide response during the first growing season and a lower portion of the total soil surface directly affected by tebuthiuron residues. Thus, more surface area could be available for snakeweed reestablishment in light application strips than in strips treated at the heavier rates or in untreated strips containing competing mature plants. A similar response by cheatgrass brome and by broom snakeweed was observed at low pellet densities following application of tebuthiuron pellets to Gambel oak (*Quercus gambelii* Nutt.) stands (Clary and others 1984).

In the third growing season (1982), the broom snakeweed suffered roughly 50 percent mortality in the treated strips. This may have occurred because the expanding seedling root systems encountered additional tebuthiuron soil residues. In the fourth growing season (1983), considerable natural mortality occurred as evidenced by the reduction in snakeweed plants in both treated and untreated strips. Significantly lower amounts of snakeweed in the heavy treatment strips in 1983 suggest that tebuthiuron residues were still affecting plant populations, and that 4 years after application the residues have resulted in fewer broom snakeweed plants even though a flush of reestablishment occurred in the posttreatment period.

The cyclic nature of broom snakeweed populations described by Jameson (1970) was a factor in the results of this study. Wide fluctuations in plant numbers on treated and untreated strips testify to the high rates of seedling establishment and high rates of natural mortality to be expected in these populations. Such fluctuations blur the evaluation of treatment response and cast some doubt on the long-term effectiveness of broom snakeweed treatment by pelleted herbicide. The wettable powder formulation of tebuthiuron may be more effective against broom snakeweed (Sosebee and others 1979) as it would leave a much smaller portion of the soil surface unaffected by herbicide. However, pelleted tebuthiuron was effective in controlling broom snakeweed in Texas (Jacoby and others 1982). Part of the apparent difference in response compared to the current study may have been related to the difference in seasonal distribution of precipitation. Areas such as west Texas and New Mexico, which have predominantly summer precipitation may also have greater broom snakeweed root activity in the surface soil layers where the herbicide residues are concentrated (Richard Bjerregaard, personal communication, 1984). Higher rates of pelleted tebuthiuron (≥ 2 lb/acre or 2.2 kg/ha) in the current study would probably have provided more effective control (Alley and Humburg 1978; Johnsen and Madrigal 1979), but rates that high have severe effects on herbaceous vegetation in the area (Clary and others, 1985).

A potential user should keep in mind that, in general, tebuthiuron effectiveness against both target and nontarget plant species increases as soil texture becomes more sandy and decreases as clay and organic matter increase (Duncan and Scifres 1983). Therefore, application rates should be adjusted with environmental considerations such as soils and precipitation in mind.

Response of Plant Production

Total plant production (herbage plus leaf and twig growth of shrubs) on the treated strips was not significantly different ($P>0.05$) from the control strip in the second, third, or fourth growing seasons after herbicide application (total production was not determined the first growing season) (table 2). There appeared to be some increase in annual grasses in the herbicide-treated area relative to the untreated area in the third and fourth seasons such as occurred on a juniper control study site (Clary and others, 1985), but the trend was not significant ($P>0.05$). Perennial grasses, principally Fairway wheatgrass, were suppressed by the herbicide the first growing season ($P<0.05$) but exhibited no significant effect in succeeding years. Forbs occurred in such small amounts on the study area that statistical detection of change was not feasible.

The most prominent change was a reduction in production of shrubs. Total shrub production was significantly reduced ($P<0.05$) by all herbicide application rates in 1981 and 1983 (no shrub production data were taken in 1980). The primary shrub species, broom snakeweed and mountain big sagebrush, were strongly reduced by the herbicide (table 3). However, the highly irregular distribution of plants on the study area made statistical detection of treatment effects difficult. Erratic distribution of large numbers of newly established broom snakeweed seedlings (table 1) resulted in no significant able 2.—Production (lb/acre) by plant group, year, and tebuthiuron application rate

	Active ingredient (lb/acre)			
ear	0	0.6	0.9	1.2
nnual grass				
980	4a[1]	8a	6a	7a
981	0a	36a	20a	26a
982	21a	148a	180a	203a
983	83a	294a	215a	137a
erennial grass				
980	201a	106b	73b	58b
981	188a	147a	105a	62a
982	227a	358a	240a	202a
983	441a	348a	252a	295a
orbs				
1980	4a	2a	2a	4a
1981	0a	0a	0a	0a
1982	11a	1a	4a	4a
1983	8a	4a	3a	5a
hrubs				
1980	—	—	—	—
1981	130a	26b	14b	9b
1982	98a	81a	26a	10a
1983	83a	21b	4b	1b
Total				
1980	—	—	—	—
1981	318a	209a	139a	97a
1982	357a	588a	450a	419a
1983	615a	667a	474a	438a

[1] Values followed by different letters within lines are significantly different at $P<0.05$.

$(P>0.05)$ shrub differences among treatments in 1982, although trends among treatment means were similar to those of 1981 and 1983. By 1983, the herbicide residues had apparently increased the mortality of the developing snakeweed plants (expanding root systems encountering herbicide pellet residues), so significant differences were again present in 1983.

Table 3.—Production (lb/acre) by principal shrub species, year, and tebuthiuron application rate

	Active ingredient (lb/acre)			
Year	0	0.6	0.9	1.2
Mountain big sagebrush				
1980	—	—	—	—
1981	28aa[1]	0aa	0aa	0aa
1982	53aa	6aa	0aa	0aa
1983	62aa	14bb	0bb	0bb
Broom snakeweed				
1980	—	—	—	—
1981	102a[2]	24b	14b	9b
1982	45aa	74aa	25aa	8aa
1983	20a	7b	4b	1b

[1] Values followed by different double letters within lines are significantly different at $P<0.10$.

[2] Values followed by different single letters within lines are significantly different at $P<0.05$.

General conclusions of the authors based on statistically significant and nonsignificant data trends and on general observation of the treatment areas are:

1. Pelleted tebuthiuron will likely reduce established broom snakeweed stands. But at herbicide application rates up to 1.2 lb/acre a.i., reestablishment of seedlings on the portions of soil surface without herbicide residue may initially compensate for the loss.
2. The cyclic nature of broom snakeweed populations may result in rapid reestablishment after herbicide treatment, or natural mortality may result in regularly occurring reductions in snakeweed populations with or without herbicide.
3. Perennial grasses, principally Fairway wheatgrass, were initially reduced as a result of herbicide application, and after several years annual grasses became more visually apparent on treated sites.
4. There is questionable benefit in using the pelleted form of tebuthiuron for control of broom snakeweed in the Intermountain area for situations similar to the test site.

REFERENCES

Alley, H. P.; Humburg, N. E. Broom snakeweed control and grass response to herbicide treatments. Research Progress Report. Project 2: herbaceous weeds of range and forest; 1978 March 14-16. Sparks, NV: Western Society of Weed Science; 1978: 12-13.

Clary, Warren P.; Goodrich, Sherel; Smith, Benton M. Response to tebuthiuron by Utah juniper and mountain big sagebrush communities. Journal of Range Management. 38: 56-60; 1985.

Clary, Warren P.; Goodrich, Sherel; Smith, Benton M. Response of Gambel oak to tebuthiuron application in central Utah. Provo, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Shrub Sciences Laboratory; 1984. 13 p.

Couey, Faye M. Antelope foods in southeastern Montana. Journal of Wildlife Management. 10: 367; 1946.

Davis, Charles A.; Barkley, Robert C.; Haussamen, Walter C. Scaled quail foods in southeastern New Mexico. Journal of Wildlife Management. 39: 496-502; 1975.

Duncan, K. W.; Scifres, C. J. Influence of clay and organic matter of rangeland soils on tebuthiuron effectiveness. Journal of Range Management. 36: 295-297; 1983.

Elanco Products Company. Graslan technical manual. Indianapolis, IN: Elanco Products Company; 1983.

Jacoby, Pete W.; Ueckert, Darrell N.; Hartmann, F. Steve. Control of creosotebush (*Larrea tridentata*) with pelleted tebuthiuron. Weed Science. 30: 307-310; 1982.

Jameson, Donald A. Competition in a blue grama-broom snakeweed-actinea community and responses to selective herbicides. Journal of Range Management. 19: 121-124; 1966.

Jameson, Donald A. Value of broom snakeweed as a range condition indicator. Journal of Range Management. 23: 302-304; 1970.

Johnsen, Thomas N., Jr. Snakeweed, broomweed (*Gutierrezia sarothrae* [Pursh.] Britt. and Rusby and/or *G. microcephala* [DC] Gray). In: Chemical control of range weeds. Washington, DC: U.S. Department of Agriculture and U.S. Department of the Interior; 1966: 11-12.

Johnsen, T. N., Jr.; Madrigal, R. M. Control of broom snakeweed with picloram, tebuthiuron, and triclopyr. Research Progress Report. Project 3: undesirable woody plants; 1979 March 20-22. Boise, ID: Western Society of Weed Science; 1979: 40.

Smith, Arthur D.; Beale, Donald M. Pronghorn antelope in Utah: some research and observations. Publication No. 80-13. Salt Lake City, UT: Utah Division of Wildlife Resources; 1980. 88 p.

Sosebee, Ronald E.; Boyd, W. E.; Brumley, C. S. Broom snakeweed control with tebuthiuron. Journal of Range Management. 32: 179-182; 1979.

Sosebee, Ronald E.; Seipp, Wayne W.; Alliney, Jorge. Broom snakeweed control on southwestern rangelands. In: 35th annual meeting, Society for Range Management; 1982 February 7-12; Calgary, AB; 1982: 22. Abstract.

Sperry, O. E.; Dollahite, J. W.; Hoffman, G. O.; Camp, B. J. Texas plants poisonous to livestock. Texas Agriculture Experiment Station Bulletin 1028. College Station, TX: Texas Agricultural and Mechanical College; 1964. 59 p.

Ueckert, Darrell N. Broom snakeweed: effect on shortgrass forage production and soil water depletion. Journal of Range Management. 32: 216-220; 1979.

.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10530

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

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 231 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.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

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

nited States
epartment of
griculture

orest Service

ntermountain
esearch Station
gden, UT 84401

esearch Note
NT-351

pril 1985

Response of Gambel Oak to Tebuthiuron in Central Utah

Warren P. Clary
Sherel Goodrich
Benton M. Smith[1]

BSTRACT

Tebuthiuron was aerially applied on a Gambel oak and at rates of 1.1, 2.1, and 3.2 lb/acre (1.2, 2.4, and 6 kg/ha) active ingredient. Control of Gambel oak xceeded 98 percent for all treatments the third growing eason after application. Total understory production as reduced by the 2.1 and 3.2 lb/acre rates, while eatgrass brome greatly increased under the 1.2 lb/acre te.

EYWORDS: tebuthiuron, herbicide, Gambel oak,
Quercus gambelii

Gambel oak (*Quercus gambelii* Nutt.) occurs almost ntirely within Arizona, Colorado, New Mexico, and tah (Little 1971). It is a rhizomatous species that typi- ally is found in dense, clonal, shrublike clumps in the orthern and middle portions of its range, and often ith treelike stature in more open stands in the southern ortion of its range.

When clonal groups are contiguous or nearly so, large reas may be almost impenetrable. Thus, objectives of nd managers may include reductions in Gambel oak ensity or continuity in order to increase livestock rage (Marquiss 1969), to improve habitat diversity for ildlife (Steinhoff 1978), or perhaps to increase water ield (Grover and others 1970). Although burning, echanical, and chemical techniques have been used to emove Gambel oak stems, it is a very persistent species at sprouts readily from an extensive underground tructure (Engle and others 1983).

Tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]- ,N′-dimethylurea) has effectively controlled many other ak species. Application rates of 2.0 lb/acre (2.2 kg/ha) ctive ingredient (a.i.) controlled 100 percent of the lackjack oak (*Q. marilandica* Muenchh.) on a fine sandy am site in Oklahoma (Shroyer and others 1979). In Texas, 0.8 lb/acre (1 kg/ha) of tebuthiuron provided effective control of sand shinnery oak (*Q. havardii* Rydb.) on fine sand sites (Pettit 1979; Jacoby and others 1983). Post oak (*Q. stellata* Wangenh.), blackjack oak, and water oak (*Q. nigra* L.) canopies were reduced 98 to 100 percent in most situations by 2.0 lb/acre (2.2 kg/ha) in the post oak savannah of Texas (Scifres and others 1981a). Tebuthiuron was effective in controlling shrub live oak (turbinella oak, *Q. turbinella* Greene) on clayey soils in Arizona (Davis and others 1980). Control of woody overstory species has often resulted in a severalfold increase in forage, particularly if tebuthiuron was applied at 2.0 lb/acre (2.2 kg/ha) or less (Pettit 1979; Scifres and Mutz 1978; Scifres and others 1981b).

Tebuthiuron did not control Gambel oak at rates of 0.7 to 2.2 lb/acre (0.8 to 2.5 kg/ha) on heavy-textured shale-derived soils in southwestern Colorado, and understory herbage production was depressed (Bartel and Rittenhouse 1982). Britton and Sneva (1981) also reported sensitivity of cool-season herbaceous plants to tebuthiuron in the Intermountain region.

The objectives of this investigation were to evaluate tebuthiuron for control of Gambel oak on a central Utah site and to evaluate the response of herbaceous and shrubby understory species.

METHODS

The test site was in Millard County, Utah, about 6 mi (10 km) south of Scipio. Average annual precipitation is 15 inches (38 cm), the major portion falling October to May. In the 3 years following herbicide application, precipitation averaged 54, 1, and 62 percent above the long-term mean, based on records from nearby communities. The test site was on a uniform alluvial-colluvial fan at the base of the Pavant Mountains at 5,800 ft (1 770 m) elevation. The surface soils were sandy loams to gravelly sandy loams developed from quartzite parent rocks. Soil texture ratios of sand:silt:clay varied from 62:28:10 with 8 percent gravel under Gambel oak clumps to 77:15:8 with 20 percent gravel in the interclump areas. Organic matter in the surface soil was about 9 percent under the oak and about 5 percent between oak clumps.

---

[1]Authors are supervisory range scientist, Forestry Sciences Laboratory, SDA Forest Service, Boise, ID; range conservationist, Vernal Ranger istrict, Ashley National Forest, USDA Forest Service, Vernal, UT; and nge conservationist, Fillmore Ranger District, Fishlake National orest, USDA Forest Service, Fillmore, UT.

In October 1979, pellets containing 40 percent a.i. tebuthiuron were aerially applied to parallel strips 168 ft (51 m) wide and 0.25 mi (0.4 km) long at rates of 1.1, 2.1, and 3.2 lb/acre (1.2, 2.4, and 3.6 kg/ha). Each rate was applied to a single strip oriented on the contour. Buffer zones 100 ft (30 m) wide were located between test strips. The sequence of strips, including a control strip, was randomized. The 0.25-mi (0.4-km) strips were assumed to adequately represent the plant community's response to each tebuthiuron rate; however, because the strips were not replicated no statistical inferences are presented.

Vegetation response was sampled during late July in 1980, 1981, and 1982. Each strip was systematically sampled by 30 sets of nested temporary plots. A set consisted of two concentric circular plots—a 1,075.8-ft^2 (100-m^2) plot for sampling damage to Gambel oak (percent dead crown), and a 9.6-ft^2 (0.9-m^2) plot for sampling herbaceous vegetation and shrub leaf and twig production. Individual oak stems over 5 ft (1.5 m) tall were categorized into 5-ft (1.5-m) height classes. Oak stems less than 5 ft (1.5 m) tall were classified collectively as "sprouts" and given one damage rating for the plot.

Herbage production was determined by weight estimate. Every fifth plot was clipped, ovendried, and weighed as a basis for correction of estimated wet weight to a dry weight basis.

RESULTS AND DISCUSSION

Because of the poor response reported by Bartel and Rittenhouse (1982), we did not expect Gambel oak to respond quickly to tebuthiuron application. However, phytotoxicity symptoms appeared the first growing season. Defoliation exceeded 40 percent for all application rates by midseason (table 1). The Gambel oak experienced several defoliation-refoliation cycles the first growing season as described by Scifres and others (1981a). The greater the herbicide rate, the more rapidly the cycle occurred.

Treatments were first evaluated the third week in July 1980. At that time the oak subjected to the heaviest rate of tebuthiuron had already defoliated and had regrown some leaves. This resulted in a lower crown damage or defoliation rating than for plants subjected to lower herbicide rates (table 1). Crown kill and apparent plant kill ranged from 74 to 98 percent the second growing season. In the third growing season, plant kill was 98 to 99 percent for all application rates. No data were collected the fourth growing season, but observations in June 1983 indicated 100 percent Gambel oak plant kill under the 2.1 and 3.2 lb/acre (2.4 and 3.6 kg/ha) rates and near 100 percent kill under the 1.1 lb/acre (1.2 kg/ha) rate with only an occasional live stem present.

There was no evidence of variation in susceptibility to tebuthiuron among height classes of oak stems. This is not surprising considering the underground structure of Gambel oak. Unpublished data show a greater biomass below ground than above ground, and that all stems in a clonal group (clump) are tied together by an intensive interconnected network of lignotubers, rhizomes, and roots. These structures appear to graft readily, facilitating the transfer of herbicide throughout the clonal system. Thus, all stems may be potentially affected to a similar degree particularly if death occurs to all or nearly all of the underground system.

The understory in the test area was depauperate, with few species and little production. This understory plant community was strongly affected by the herbicide in each of the three posttreatment years (table 2). In 1982, the third year after application, the two highest application rates still depressed production of the forb and shrub groups and total understory production. Mountain big sagebrush (*Artemisia tridentata vaseyana* [Rydb.] Beetle), which was severely reduced by all application rates, was the understory plant most sensitive to the herbicide. Broom snakeweed (*Xanthocephalum sarothrae* [Pursh] Shinners), which had its highest production in the light treatment strip, was perhaps the plant least affected by the herbicide. This may be in part because broom snakeweed, with its less extensive root system, was not as susceptible as large shrubs to the distribution pattern of 40 percent a.i. pellets; therefore, many old and new snakeweed plants could respond to release from oak overstory dominance.

Annual grasses, principally cheatgrass brome (*Bromus tectorum* L.), increased in the light treatment strip (1.1 lb/acre or 1.2 kg/ha) in 1982 after death of the Gambel oak overstory, but decreased on the area treated at the 3.2 lb/acre (3.6 kg/ha) rate (table 2). The highest application rate with its correspondingly higher pellet density on the soil surface would directly affect more of the cheatgrass plants—approximately one pellet vs. three pellets per 2 ft^2 (0.2 m^2) (Elanco Products Company 1983).

This study area, with its coarse-textured soils, was one on which tebuthiuron was exceptionally effective against Gambel oak. Many sites, perhaps most sites, would likely not experience such a high rate of oak control at the same application rates. Observation suggests that most Gambel oak sites would have finer textured soils and, most likely, higher amounts of soil organic matter, both of which reduce effectiveness of tebuthiuron (Chang and Stritzke 1977; Duncan and Scifres 1983).

The few understory perennial plants originally under the oak stand were also severely affected by the herbicide. These and similar results on a nearby pinyon-juniper (*Pinus-Juniperus*) tebuthiuron test area (Clary and others 1985) and results from related areas (Bartel and Rittenhouse 1982; Britton and Sneva 1981) suggest that application rates sufficiently high to remove tree-size woody overstories will be very damaging to native perennial forage plants in the Intermountain region. This

Table 1.—Percentage Gambel oak defoliation (1980, 1981) and plant kill (1982) by tebuthiuron in central Utah

	Tebuthiuron, lb/acre (kg/ha)			
Year	Control	1.1(1.2)	2.1(2.4)	3.2(3.6)
1980	0	58.6	70.8	49.8
1981	0	74.3	93.7	98.2
1982	0	99.3	99.6	98.6

Table 2.—Understory species production after application of 40 percent of active ingredient tebuthiuron pellets to a Gambel oak community

	Active ingredient, lb/acre (kg/ha)											
	1980				1981				1982			
Species	**Control**	**1.1(1.2)**	**2.1(2.4)**	**3.2(3.6)**	**Control**	**1.1(1.2)**	**2.1(2.4)**	**3.2(3.6)**	**Control**	**1.1(1.2)**	**2.1(2.4)**	**3.2(3.6)**
	Lb/acre											
ANNUAL GRASSES												
Cheatgrass brome (*Bromus tectorum L.)*	36	13	6	4	3	11	5	0	214	548	214	95
Others	0	0	0	0	0	0	0	0	1	1	0	1
Total	36	13	6	4	3	11	5	0	215	549	214	96
PERENNIAL GRASSES												
Bluebunch wheatgrass (*Agropyron spicatum* [Pursh] Scribn. and Sm.)	2	2	2	0	0	7	0	0	1	5	0	0
Sandberg bluegrass (*Poa secunda* Presl.)	5	9	9	8	0	0	0	0	5	6	2	0
Bottlebrush squirreltail (*Sitanion hystrix* [Nutt.] J. G. Sm.)	T	1	0	0	0	0	0	0	3	2	1	1
Others	2	0	T	0	0	0	0	0	2	3	0	1
Total	9	12	11	8	0	7	0	0	11	16	3	2
FORBS												
Peavine (*Lathyrus brachycalyx* Rydb.)	0	0	0	0	0	0	0	0	29	7	0	0
Others	7	2	1	2	0	0	0	0	1	19	1	1
Total	7	2	1	2	0	0	0	0	30	26	1	1
SHRUBS												
Mountain big sagebrush (*Artemisia tridentata vaseyana* [Rydb.] Beetle)	46	1	2	0	25	0	0	0	113	1	0	0
Broom snakeweed (*Xanthocephalum sarothrae* [Pursh] Shinners)	3	1	1	0	2	9	8	3	7	69	11	7
Others	0	2	0	0	0	0	0	0	0	0	0	T
Total	49	4	3	0	27	9	8	3	120	70	11	7
GRAND TOTAL	101 (113 kg/ha)	31 (35 kg/ha)	21 (24 kg/ha)	14 (16 kg/ha)	30 (34 kg/ha)	27 (30 kg/ha)	13 (15 kg/ha)	3 (3 kg/ha)	376 (421 kg/ha)	661 (741 kg/ha)	229 (257 kg/ha)	106 (119 kg/ha)

result is different from that experienced in Texas where perennial forages regularly increase severalfold following tebuthiuron application to oak stands.

In the central Intermountain area reseeding would need to follow most tebuthiuron broadcast Gambel oak treatments to attain a productive forage stand. The combined expense of the herbicide treatment and reseeding may eliminate the use of tebuthiuron on a broad scale. A more likely use of tebuthiuron may be for localized control of Gambel oak to establish travel corridors through dense stands and to develop openings for various uses.

ACKNOWLEDGMENTS

Authors acknowledge Richard Bjerregaard, representative of Eli Lilly and Company, for his assistance and for materials furnished for this study.

REFERENCES

Bartel, Lawrence E.; Rittenhouse, Larry R. Effects of tebuthiuron on Gambel oak and associated understory vegetation. In: 35th annual meeting, Society for Range Management; 1982 February 7-12; Calgary, AB; 1982: 19. Abstract.

Britton, C. M.; Sneva, F. A. Effects of tebuthiuron on western juniper. Journal of Range Management. 34: 30-32; 1981.

Chang, S. S.; Stritzke, J. F. Sorption, movement, and dissipation of tebuthiuron in soils. Weed Science. 25: 184-187; 1977.

Clary, Warren P.; Goodrich, Sherel; Smith, Benton M. Response to tebuthiuron by Utah juniper and mountain big sagebrush communities. Journal of Range Management. 38: 56-60; 1985.

Davis, E. A.; Kieger, N.; Bryant, B. A. Tests of soil-applied chemicals for chaparral management in Arizona. In: Research progress report, project 3: undesirable woody plants; 1980 March 18-20; Salt Lake City, UT. Salt Lake City, UT: Western Society of Weed Science; 1980: 77-79.

Duncan, K. W.; Scifres, C. J. Influence of clay and organic matter of rangeland soils on tebuthiuron effectiveness. Journal of Range Management. 36: 295-297; 1983.

Elanco Products Company. Graslan technical manual. Indianapolis, IN: Elanco Products Company; 1983.

Engle, D. M.; Bonham, C. D.; Bartel, L. E. Ecological characteristics and control of Gambel oak. Journal of Range Management. 36: 363-365; 1983.

Grover, B. L.; Campbell, C. B.; Campbell, M. D. A prediction for vegetation effects on water yield from watersheds in arid areas. Soil Science Society of America Proceedings. 34: 669-673; 1970.

Jacoby, P. W.; Slosser, J. E.; Meadors, C. H. Vegetational responses following control of sand shinnery oa with tebuthiuron. Journal of Range Management. 36: 510-512; 1983.

Little, E. L., Jr. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. Miscellaneous Publication 1146. Washington, DC: U.S. Department of Agriculture, Forest Service; 1971.

Marquiss, R. W. Studies on Gambel's oak at the San Juan Basin Station. Fort Collins, CO: Colorado State University Agricultural Experiment Station; 1969; Progress Report 69-38. 2 p.

Pettit, R. D. Effects of picloram and tebuthiuron pellet on sand shinnery oak communities. Journal of Range Management. 32: 196-200; 1979.

Scifres, C. J.; Mutz, J. L. Herbaceous vegetation changes following applications of tebuthiuron for brus control. Journal of Range Management. 31: 375-378; 1978.

Scifres, C. J.; Stuth, J. W.; Bovey, R. W. Control of oa (*Quercus* spp.) and associated woody species on rangeland with tebuthiuron. Weed Science. 29: 270-27 1981a.

Scifres, Charles J.; Stuth, Jerry W.; Kirby, Donald R.; Angell, Raymond F. Forage and livestock production following oak (*Quercus* spp.) control with tebuthiuron Weed Science. 29: 535-539; 1981b.

Shroyer, J. P.; Stritzke, J. F.; Oroy, L. I. Carbohydrate levels and control of blackjack oak and winged elm treated with tebuthiuron and 2,4,5-T. Journal of Rang Management. 32: 60-62; 1979.

Steinhoff, Harold W. Management of Gambel oak asso ations for wildlife and livestock. 1978. Unpublished report on file at U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Denver, CO 119 p.

---

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/10533

nited States
epartment of
griculture

orest Service

**termountain
esearch Station
gden, UT 84401**

esearch
ote INT-352

ctober 1985

A Computer Software System for Entering, Managing, and Analyzing Fish Capture Data from Streams

**John S. Van Deventer
William S. Platts[1]**

BSTRACT

A microcomputer software system called the "Fisheries opulation and Statistical Package" (FPSP) is intended r use in entering, managing, and analyzing fish capture ata from streams. The system, written in the BASIC nguage, facilitates data entry with prompts and edit- g during input. Once entered, data can be further rganized with enhanced editing allowing for additions, eletions, and modifications of observations. The data ts created may be copied, printed, or displayed on the mputer terminal. Data analysis is the main feature of PSP. Nineteen categories of calculations are performed cluding total catch, maximum-likelihood population timates, capture probabilities, lengths, and weights. PSP allows multiple study sites to be compared simul- neously for study purposes. An example of FPSP sys- m output is provided. The BASIC code for an bbreviated, interactive version of FPSP is included, ong with an example of printed output.

EYWORDS: fisheries, data analysis, computer software, electrofishing, microcomputer, population estimation

The Fisheries Population and Statistical Package PSP) consists of four software programs developed in e BASIC language for the IBM personal computer. e purpose of FPSP is to provide quick and accurate entry, management, and analysis of fish capture data gathered by a removal-depletion electrofishing effort. Computer automation of this process reduces the chance of transcription errors, facilitates data editing, and eliminates the tedium and possible human error in statistical analysis. FPSP provides a variety of calculations and data comparison options that enhance the researcher's perspective regarding the significance of the data. In short, the time, effort, and money that previously had been spent processing results may now be invested interpreting the results.

SYSTEM CAPABILITIES

The three main performance capabilities of FPSP are data entry, data management, and data analysis.

Data Entry

Fish capture data can be entered directly into the computer using FPSP's Data Management Program. This program prompts the user to assign a file name to the data set and then asks the user to input essential data (removal number, species number, length, and weight) for each fish collected. Editing statements are included to detect and correct invalid entries.

Data Management

Following the initial data input, the user may select an option from a menu to:

1. Modify observations
2. Add or delete observations
3. Print or display formatted data
4. Create new data sets
5. Copy existing data sets.

---

[1] The authors are computer specialist and research fishery biologist, pectively, Intermountain Research Station, Forestry Sciences oratory, Boise, ID 83702. This paper in part fulfilled M.S. degree sis requirements for John S. Van Deventer.

Data Analysis

Most of the FPSP system is dedicated to data analysis. FPSP allows the user to define multiple "study sites" within a "study area." A stream, for example, might be divided into three segments, which together are the study area. Data analysis is performed both by study site and by study area for the purpose of comparison.

The following calculations are performed for (a) individual species within each study site, (b) individual species in the study area, (c) the total of all species within each study site, and (d) the total of all species in the study area:

1. Total catch
2. Total catch percentages
3. Maximum-likelihood population estimates
4. Population estimate percentages
5. Population estimate standard errors
6. Population estimate 95 percent confidence intervals
7. Capture probabilities
8. Capture probability standard errors
9. Capture probability 95 percent confidence intervals
10. Chi-square goodness of fit on the maximum-likelihood estimates
11. Condition factors
12. Average lengths
13. Length standard errors
14. Length 95 percent confidence intervals
15. Total weights
16. Total weight percentages
17. Average weights
18. Weight standard errors
19. Weight 95 percent confidence intervals.

See appendix A for an example of FPSP's output.

SPECIAL FEATURES

Five special features are included in the FPSP system.

Maximum-Likelihood Estimation

Computer automation of the data analysis has made it possible to incorporate the use of a sophisticated maximum-likelihood population estimate model developed by Dr. Kenneth P. Burnham of North Carolina State University (Van Deventer and Platts 1983). This method provides accurate population estimates by calculating the likelihood of every possible population estimate equal to or greater than the total catch until the estimate of greatest likelihood is reached. The number of calculations involved makes this iterative process impractical with a hand calculator. The maximum-likelihood estimate is applicable to fish capture data involving two or more electrofishing removals. Generally, the more removals, the narrower the confidence intervals are around the population estimate.

Calculation Speed and Accuracy

Calculation time is minimized with FPSP because no manual computations are required; hence, program calcul tions should also be highly accurate. On an average-sized data set FPSP will perform approximately 21,500 calcula tions in a little over 2 minutes.

Comparisons Between Study Sites

The ability to compare study sites is an important feature of FPSP. Because the user defines what constitutes study site, a variety of research options are available. Fo example, different streams in the same watershed can be compared with one another. The same stream may be co pared with itself from one year to the next for time-trenc analysis. Or suppose we defined three adjacent sites on a stream—a treatment site surrounded by two control sites—all of equal stream length. FPSP has the ability tc compare the numbers of fish in each site. Furthermore, i habitat deterioration is suspected in the treatment site, comparisons can be made to assess species composition, fish weights, and condition factors.

System Adaptability

FPSP was designed to accommodate the widest possib range of experimental conditions.

1. FPSP manages one or more study sites per study area. (Note: Although FPSP performs calculations on an number of study sites, only three sites will be printed or 80-column paper and six sites on 132-column paper.)

2. FPSP performs calculations individually and corporately for any number of species encountered.

3. FPSP accommodates special data-handling needs. For example, it may not be desirable to measure the length and weight of nongame fish individually. In such cases the option exists to enter the total number of non game fish and the total weight as a single observation. special "species file" allows the user to distinguish between game and nongame fish.

4. FPSP allows the user to select the calculations th are to be printed from an output menu.

An Interactive Version of FPSP

For those desiring immediate population results, the FPSP Interactive Program is available (see appendix B) This program prompts the user for stream name, specie name, the number of removals, and the number of fish caught on each removal. The output includes total catcl maximum-likelihood population estimate, capture probal ity, chi-square, and standard errors and confidence inter vals for both the population estimate and the capture probability (see appendix C). The length and weight dat are not considered in this abbreviated program.

ECHNICAL CONSIDERATIONS

Maximum-likelihood population estimates based on a moval-depletion strategy assume (Zippin 1958):

1. No animals enter or leave the study area.
2. Each individual has an equal chance of being ptured.
3. The probability of capture remains the constant with ch removal.

he maximum-likelihood estimate and those statistics as- ciated with it are detrimentally impacted by a lack of herence to these assumptions. The chi-square test, the nfidence intervals around the population estimate, and e capture probability are indicators of how well these as- mptions have been met. If there is an abnormally low pture probability, a highly variable capture probability, a nondescending removal pattern, the maximum- elihood calculation will terminate at five times the total tch and a warning message will be displayed.

FPSP does not require an entire study site to be electro- shed at one time. For example, a 100-m length of stream ay be broken into five 20-m segments to facilitate ectrofishing.

FPSP was written for an IBM Personal Computer XT sing Disk Operating System (DOS) Version 2.1. It will resumably work on an IBM PC, an IBM PC AT, or an BM PC-compatible computer with DOS 2.0, DOS 2.1, or OS 3.0. FPSP requires a minimum of 256 kilobytes (K) f random access memory (RAM). Large data sets may re- uire more memory.

EFERENCES

an Deventer, J. S.; Platts, W. S. Sampling and estimating fish populations from streams. Transactions of the North American Wildlife and Natural Resources Conference. 48: 349-354; 1983.

ippin, C. The removal method of population estimation. Journal of Wildlife Management. 22(1): 82-90; 1958.

APPENDIX A: EXAMPLE OF OUTPUT FROM FPSP SYSTEM

```
=================================================================================
FISH SAMPLING RESULTS
TITLE:  South Fork Salmon R. 10/15/84     Number of Sites      =  3
FILE:   FISH.DAT                          Number of Removals =  4
DATE:   11-04-84    7:11 p.m.             Number of Species    =  3
=================================================================================


                     FISH CAPTURE TOTALS (% by Species)
SPECIES              SITE = 1      SITE = 2      SITE = 3         TOTAL
---------------------------------------------------------------------------------
                | #FISH    %   | #FISH    %   | #FISH    %   || #FISH    %
---------------------------------------------------------------------------------
                |              |              |              ||
Rainbow Trout   |  169   42.0% |   72   17.9% |  161   40.0% ||  402  100.0%
Cutthroat Trout |   44   34.1% |   20   15.5% |   65   50.4% ||  129  100.0%
Sucker          |   18   10.6% |  133   78.2% |   19   11.2% ||  170  100.0%
                |              |              |              ||
---------------------------------------------------------------------------------
TOTAL           |  231   33.0% |  225   32.1% |  245   35.0% ||  701  100.0%
---------------------------------------------------------------------------------


                      FISH CAPTURE TOTALS (% by Site)
SPECIES              SITE = 1      SITE = 2      SITE = 3         TOTAL
---------------------------------------------------------------------------------
                | #FISH    %   | #FISH    %   | #FISH    %   || #FISH    %
---------------------------------------------------------------------------------
                |              |              |              ||
Rainbow Trout   |  169   73.2% |   72   32.0% |  161   65.7% ||  402   57.3%
Cutthroat Trout |   44   19.0% |   20    8.9% |   65   26.5% ||  129   18.4%
Sucker          |   18    7.8% |  133   59.1% |   19    7.8% ||  170   24.3%
                |              |              |              ||
---------------------------------------------------------------------------------
TOTAL           |  231  100.0% |  225  100.0% |  245  100.0% ||  701  100.0%
---------------------------------------------------------------------------------


                    POPULATION ESTIMATES (% by Species)
SPECIES              SITE = 1      SITE = 2      SITE = 3         TOTAL
---------------------------------------------------------------------------------
                |  EST     %   |  EST     %   |  EST     %   || TOTAL  %   EST
---------------------------------------------------------------------------------
                |              |              |              ||
Rainbow Trout   |  175   41.9% |   75   17.9% |  168   40.2% ||  418 100%  420
Cutthroat Trout |   45   33.8% |   21   15.8% |   67   50.4% ||  133 100%  135
Sucker          |   18   10.1% |  142   79.3% |   19   10.6% ||  179 100%  180
                |              |              |              ||
---------------------------------------------------------------------------------
SITE ESTIMATES  |  239   32.5% |  240   32.7% |  256   34.8% ||  737 100%  735
---------------------------------------------------------------------------------
```

(con

POPULATION ESTIMATES (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	EST	%	EST	%	EST	%	EST	%
Rainbow Trout	175	73.5%	75	31.5%	168	66.1%	420	57.1%
Cutthroat Trout	45	18.9%	21	8.8%	67	26.4%	135	18.4%
Sucker	18	7.6%	142	59.7%	19	7.5%	180	24.5%
ESTIMATE TOTALS	238	100.0%	238	100.0%	254	100.0%	735	100.0%
SITE ESTIMATES	239		240		256		735	

POPULATION ESTIMATE STANDARD ERRORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	3.524	2.691	3.953	6.161
Cutthroat Trout	1.518	1.946	2.264	3.658
Sucker	0.879	4.909	0.829	5.034
SITE STD ERROR	4.067	6.220	4.899	8.889

POPULATION ESTIMATE 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	169, 182	72, 80	161, 176	408, 432
Cutthroat Trout	44, 48	20, 25	65, 72	129, 142
Sucker	18, 20	133, 152	19, 21	170, 190
SITE ESTIMATES	231, 247	228, 252	246, 266	720, 754

CAPTURE PROBABILITIES

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	0.5615	0.5373	0.5403	0.5425
Cutthroat Trout	0.5867	0.4878	0.5556	0.5353
Sucker	0.6000	0.4926	0.6129	0.5075
SITE TOTAL	0.5634	0.4967	0.5396	0.5291

(con.)

APPENDIX A: (Con.)

CAPTURE PROBABILITY STANDARD ERROR

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	0.0389	0.0613	0.0408	0.0257
Cutthroat Trout	0.0745	0.1233	0.0634	0.0458
Sucker	0.1158	0.0471	0.1110	0.0411
SITE CAPT S.E.	0.0332	0.0361	0.0331	0.0197

CAPTURE PROBABILITY 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	0.4848, 0.6382	0.4153, 0.6593	0.4599, 0.6206	0.4918, 0.5932
Cutthroat Trout	0.4367, 0.7366	0.2313, 0.7443	0.4291, 0.6820	0.4446, 0.6259
Sucker	0.3566, 0.8434	0.3993, 0.5859	0.3805, 0.8453	0.4266, 0.5883
SITE 95% C.I.	0.4979, 0.6289	0.4257, 0.5677	0.4745, 0.6048	0.4904, 0.5678

CHI SQUARE GOODNESS OF FIT

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	0.2341	2.1172	0.1651	0.3148
Cutthroat Trout	2.2675	0.3464	0.3552	1.1650
Sucker	0.3592	0.0895	0.2925	0.1125
SITE TOTAL	0.1792	0.5107	0.2924	0.8080

CONDITION FACTORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	1.108	1.100	1.054	1.085
Cutthroat Trout	1.122	1.173	1.109	1.123
Sucker	1.086	1.089	1.071	1.087

(con.)

AVERAGE LENGTHS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	101.0	92.5	108.6	102.5
Cutthroat Trout	90.9	74.8	89.8	87.9
Sucker	92.5	102.7	98.6	101.2

LENGTH STANDARD ERRORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	2.965	4.375	2.492	1.798
Cutthroat Trout	5.501	8.099	3.927	3.018
Sucker	4.855	2.973	5.523	2.465

LENGTH 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	95.1, 106.8	83.8, 101.2	103.7, 113.6	99.0, 106.1
Cutthroat Trout	79.8, 102.0	57.8, 91.7	82.0, 97.7	81.9, 93.8
Sucker	82.3, 102.7	96.9, 108.6	87.0, 110.2	96.3, 106.1

TOTAL WEIGHTS (% by Species)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	WEIGHT	%	WEIGHT	%	WEIGHT	%	WEIGHT	%
Rainbow Trout	2622	43.2%	887	14.6%	2558	42.2%	6067	100.0%
Cutthroat Trout	515	37.8%	155	11.4%	694	50.9%	1364	100.0%
Sucker	167	7.1%	1964	83.5%	221	9.4%	2352	100.0%
TOTAL	3304	33.8%	3006	30.7%	3473	35.5%	9783	100.0%

(con.)

APPENDIX A: (Con.)

TOTAL WEIGHTS (% by Site)

SPECIES	SITE = 1		SITE = 2		SITE = 3		TOTAL	
	WEIGHT	%	WEIGHT	%	WEIGHT	%	WEIGHT	%
Rainbow Trout	2622	79.4%	887	29.5%	2558	73.7%	6067	62.0%
Cutthroat Trout	515	15.6%	155	5.2%	694	20.0%	1364	13.9%
Sucker	167	5.1%	1964	65.3%	221	6.4%	2352	24.0%
TOTAL	3304	100.0%	3006	100.0%	3473	100.0%	9783	100.0%

AVERAGE WEIGHTS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	15.5	12.3	15.9	15.1
Cutthroat Trout	11.7	7.8	10.7	10.6
Sucker	9.3	14.8	11.6	13.8

WEIGHT STANDARD ERRORS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	1.295	1.692	0.869	0.715
Cutthroat Trout	1.964	2.581	1.687	1.151
Sucker	1.182	1.188	1.614	0.964

WEIGHT 95% CONFIDENCE INTERVALS

SPECIES	SITE = 1	SITE = 2	SITE = 3	TOTAL
Rainbow Trout	13.0, 18.1	8.9, 15.7	14.2, 17.6	13.7, 16.5
Cutthroat Trout	7.7, 15.7	2.3, 13.2	7.3, 14.0	8.3, 12.9
Sucker	6.8, 11.8	12.4, 17.1	8.2, 15.0	11.9, 15.7

APPENDIX B: BASIC LANGUAGE INSTRUCTIONS FOR THE FPSP INTERACTIVE VERSION

```
1000 REM           FISHERIES POPULATION and STATISTICAL PACKAGE
1010 REM
1020 REM               POPULATION ESTIMATE PROGRAM (FPSP-3)
1030 REM                       Interactive  Version
1040 REM
1050 REM Permission to copy this program is granted under the condition that
1060 REM NO alterations be made (to prevent distribution of unauthorized
1070 REM or erroneous modifications, or both).
1080 REM
1090 REM Please contact the author
1100 REM     (1) to be kept informed of enhancements or modifications to
1110 REM             this program
1120 REM     (2) to provide any comments (positive or negative)
1130 REM     (3) if any program-related problems occur
1140 REM
1150 REM This program has been thoroughly tested and is accurate to the
1160 REM best of my knowledge.
1170 REM
1180 REM                     John S. Van Deventer
1190 REM                     USDA  Forest Service
1200 REM                     Forestry Science Lab
1210 REM                     316 E. Myrtle Street
1220 REM                     Boise, ID  83702
1230 REM
1240 REM
1250 CLS
1260 REM
1270 REM  Title page.
1280 REM
1290 KEY OFF
1300 CLR = (VAL(RIGHT$(TIME$,2)) MOD 6) + 9
1310 COLOR CLR,0
1320 STARTROW = 5
1330 STARTCOL = 10
1340 REM
1350 COLOR 15,0
1360 LOCATE  7,18 : PRINT "FISHERIES POPULATION and STATISTICAL PACKAGE "
1370 COLOR CLR,0
1380 LOCATE  9,22 : PRINT "POPULATION ESTIMATE PROGRAM (FPSP-3)"
1390 LOCATE 10,30 : PRINT "Interactive  Version"
1400 COLOR 15,0
1410 LOCATE 12,38 : PRINT "by"
1420 LOCATE 14,30 : PRINT "John S. Van Deventer"
1430 LOCATE 15,30 : PRINT "USDA  Forest Service"
1440 LOCATE 16,30 : PRINT "Forestry Science Lab"
1450 LOCATE 17,30 : PRINT "316 E. Myrtle Street"
1460 LOCATE 18,30 : PRINT "Boise, Idaho   83702"
1470 LOCATE 24,70 : INPUT "Hit ENTER ", DUMMY$
1480 DIM EXPNUMFISH(12),NUMFISHPRRMVL(12)
1490 COLOR 7,0
1500 CLS
1510 INPUT "Enter the name of the STREAM.  ",STREAM$
```

(con.)

```
1520 INPUT "Enter the name of the SPECIES.  ",SPECIES$
1530 INPUT "Enter the number of REMOVALS (electrofishing passes). ",NUMOFRMVLS
1540 T=NUMOFRMVLS
1550 FOR RMVL = 1 TO NUMOFRMVLS
1560     PRINT "How many fish caught in pass";RMVL;
1570     INPUT NUMFISHPRRMVL(RMVL)
1580     S=S+NUMFISHPRRMVL(RMVL)
1590     C=C+NUMFISHPRRMVL(RMVL)*RMVL
1600 NEXT RMVL
1610 PRINT
1620 PRINT
1630 PRINT "Processing..."
1640 PRINT
1650 PRINT
1660 REM ......................................................................
1670 FIRSTTERM = 0
1680 I = 0
1690 THETA = 0
1700 OLDTHETA = 0
1710 PHAT = S/C
1720 GOTO 1780
1730 I = I + 1
1740 IF (S + I) > (5 * S)  THEN WARNINGMSG = 1 : GOTO 1810
1750 PHAT = S/(C+T*I)
1760 FIRSTTERM = FIRSTTERM+LOG(1+S/I)
1770 OLDTHETA = THETA
1780 THETA = FIRSTTERM+S*LOG(PHAT)+(C-S+T*I)*LOG(1-PHAT)
1790 IF (OLDTHETA<THETA) OR (I=0) THEN 1730
1800 REM ......................................................................
1810 POPEST = I-1+S
1820 CAPTPROB = S/(C+T*(I-1))
1830 PHAT = CAPTPROB
1840 POPSIZVAR=POPEST*(1-PHAT)^T*(1-(1-PHAT)^T)/((1-(1-PHAT)^T)^2-(T*PHAT)^2*(1-PH
-1))
1850 SEPOPSIZ = SQR(POPSIZVAR)
1860 TVALUE = 1.96
1870 CONFINTPOP = TVALUE*SEPOPSIZ
1880 UPCONFINTPOP = POPEST+CONFINTPOP
1890 LOCONFINTPOP = POPEST - CONFINTPOP
1900 IF LOCONFINTPOP<S THEN LOCONFINTPOP = S
1910 REM ......................................................................
1920 VARCAPTPROB=(CAPTPROB/POPEST)^2*(POPSIZVAR/(1-CAPTPROB)^(T-1))
1930 SECAPTPROB = SQR(VARCAPTPROB)
1940 CONFINTCAPT = TVALUE*SECAPTPROB
1950 UPCONFINTCAPT = CAPTPROB + CONFINTCAPT
1960 LOCONFINTCAPT = CAPTPROB - CONFINTCAPT
1970 IF LOCONFINTCAPT < 0 THEN LOCONFINTCAPT = 0
1980 REM ......................................................................
1990 EXPTOTNUMFISH = TOTNUMFISHCOT = CHISQSUMTERM = 0
2000 FOR RMVL = 1 TO NUMOFRMVLS
2010     EXPNUMFISH(RMVL)= POPEST*(1-CAPTPROB)^(RMVL-1)*CAPTPROB
2020     CHISQSUMTERM=CHISQSUMTERM+(NUMFISHPRRMVL(RMVL)-EXPNUMFISH(RMVL))^2/EXPNUM
MVL)
```

(cc

APPENDIX B: (Con.)

```
2030 EXPTOTNUMFISH=EXPTOTNUMFISH+EXPNUMFISH(RMVL)
2040    TOTNUMFISHCOT = TOTNUMFISHCOT + NUMFISHPRRMVL(RMVL)
2050 NEXT RMVL
2060 CHISQUARE = CHISQSUMTERM+(TOTNUMFISHCOT-EXPTOTNUMFISH)^2/EXPTOTNUMFISH
2070 REM ......................................................................
2080 DEVICE$ = "SCRN:"
2090 OPEN DEVICE$ FOR OUTPUT AS #1
2100 IF WARNINGMSG = 1  THEN 2120  ELSE 2160
2110    PRINT #1, " "
2120    PRINT #1, "Run terminated at population estimate equal to 5 times the"
2130    PRINT #1, "total catch.  Cause:  irregular or non-descending removal"
2140    PRINT #1, "pattern.  Results should not be considered reliable."
2150    PRINT #1, " "
2160 PRINT #1, "STREAM:  " STREAM$ ;
2170 PRINT #1, TAB(45) "SPECIES:  " SPECIES$
2180 PRINT #1, " "
2190 PRINT #1, "TOTAL CATCH       = ";
2200 PRINT #1, USING "######,"; S
2210 PRINT #1, "POPULATION EST    = ";
2220 PRINT #1, USING "######,"; POPEST;
2230 PRINT #1, TAB(45) "CAPTURE PROB      = ";
2240 PRINT #1, USING "#.####"; CAPTPROB
2250 PRINT #1, "POP EST STD ERR   = ";
2260 PRINT #1, USING "###.###"; SEPOPSIZ;
2270 PRINT #1, TAB(45) "CAPT PROB STD ERR = ";
2280 PRINT #1, USING "#.####"; SECAPTPROB
2290 PRINT #1, "LOWER CONF INTRVL = ";
2300 PRINT #1, USING "######,.##"; LOCONFINTPOP;
2310 PRINT #1, TAB(45) "LOWER CONF INTRVL = ";
2320 PRINT #1, USING "#.####"; LOCONFINTCAPT
2330 PRINT #1, "UPPER CONF INTRVL = ";
2340 PRINT #1, USING "######,.##"; UPCONFINTPOP;
2350 PRINT #1, TAB(45) "UPPER CONF INTRVL = ";
2360 PRINT #1, USING "#.####"; UPCONFINTCAPT
2370 PRINT #1, " "
2380 PRINT #1, "CHI SQUARE        = ";
2390 PRINT #1, USING "####.####"; CHISQUARE
2400 PRINT #1, "REMOVAL PATTERN:  ";
2410 FOR RMVL = 1 TO NUMOFRMVLS
2420    PRINT #1, NUMFISHPRRMVL(RMVL);
2430 NEXT RMVL
2440 PRINT #1, " "
2450 PRINT #1, " "
2460 PRINT #1, " "
2470 PRINT #1, " "
2480 CLOSE #1
2490 IF PRINTFLAG = 1 THEN 2560
2500    INPUT "Do you want this PRINTED"; ANS$
2510    ANS$ = LEFT$(ANS$,1)
2520    IF ANS$ = "Y" OR ANS$ = "y"  THEN 2530  ELSE 2560
2530       PRINTFLAG = 1
2540       DEVICE$ = "LPT1:"
2550       GOTO 2090
2560 END
```

APPENDIX C: EXAMPLES OF EXECUTIONS OF THE FPSP INTERACTIVE VERSION PROGRAM

```
STREAM:  Clearwater Creek                      SPECIES:  Rainbow Trout

TOTAL CATCH         =   1,259
POPULATION EST      =   1,542                  CAPTURE PROB        = 0.4315
POP EST STD ERR     =  43.074                  CAPT PROB STD ERR = 0.0212
LOWER CONF INTRVL =     1,457.58               LOWER CONF INTRVL = 0.3899
UPPER CONF INTRVL =     1,626.42               UPPER CONF INTRVL = 0.4730

CHI SQUARE          =     2.9691
REMOVAL PATTERN:    678   352   229


STREAM:  So. Fork Salmon River                 SPECIES:  Chinook

TOTAL CATCH         =   1,924
POPULATION EST      =   1,970                  CAPTURE PROB        = 0.5270
POP EST STD ERR     =   8.672                  CAPT PROB STD ERR = 0.0104
LOWER CONF INTRVL =     1,953.00               LOWER CONF INTRVL = 0.5067
UPPER CONF INTRVL =     1,987.00               UPPER CONF INTRVL = 0.5473

CHI SQUARE          =     1.0463
REMOVAL PATTERN:    1029   502   231   115   47

STREAM:  Payette River                         SPECIES:  Cutthroat Trout

TOTAL CATCH         =   1,083
POPULATION EST      =   1,243                  CAPTURE PROB        = 0.4007
POP EST STD ERR     =  26.063                  CAPT PROB STD ERR = 0.0181
LOWER CONF INTRVL =     1,191.92               LOWER CONF INTRVL = 0.3652
UPPER CONF INTRVL =     1,294.08               UPPER CONF INTRVL = 0.4362

CHI SQUARE          =     2.3599
REMOVAL PATTERN:    486   311   189   97
```

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-576-040/20017

ed States
artment of
culture

st Service

rmountain
earch Station
en, UT 84401

earch Note
353

uary 1986

Association of an Endemic Mountain Pine Beetle Population with Lodgepole Pine Infected by Armillaria Root Disease in Utah

Borys M. Tkacz[1]
Richard F. Schmitz[2]

3STRACT

random sample of 42 mature lodgepole pines ealed a significant and consistent association between ction by the root pathogen Armillaria mellea *and the dence of infestation by low population (endemic) ls of mountain pine beetle* (Dendroctonus derosae). *Of 21 trees with visual indicators of para-* A. mellea *infection, 19 were infested by the beetle, le only three of 21 trees with no visible indicators of* nellea *were infested. This is the first documentation he association in lodgepole pine that may be an ortant factor affecting the dynamics of endemic level ulations of the beetle.*

YWORDS: *Dendroctonus ponderosae, Pinus contorta, Armillaria mellea*

INTRODUCTION

The mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) is the most destructive insect infesting lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) (Amman 1978). Infestations of MPB have reached outbreak levels throughout much of the lodgepole pine type in northern Utah (Thier and Hoffman 1982) and elsewhere in the Western United States and Canada (USDA Forest Service 1983). Because little can be done to reverse the trend of an outbreak once under way (Amman and Baker 1972), prevention of outbreaks is a sensible approach to limit tree killing. Consequently, a part of the mountain pine beetle research program funded by the U.S. Department of Agriculture, Forest Service, has been directed toward understanding the dynamics of low population (endemic) levels (Cole 1979), with the ultimate objective to develop strategies to prevent outbreaks.

Studies by Schmitz to characterize lodgepole pine infested by low population levels of MPB include measures of the incidence and severity of stem disease and insects and disease affecting the roots. Preliminary observations made in lodgepole pine stands growing in the Uinta Mountains in northeastern Utah revealed that many trees infested by endemic mountain pine beetle populations had roots infected by *Armillaria mellea*

---

lant pathologist, Forest Pest Management, Intermountain Region, t Service, U.S. Department of Agriculture, Ogden, UT.
search entomologist, Population Dynamics of the Mountain Pine e Research Work Unit, Forestry Sciences Laboratory, Intermoun- lesearch Station, Forest Service, U.S. Department of Agriculture, n, UT.

(Vahl. ex. Fr.) Kummer, sensu lato[3]. The evaluation described here was conducted to determine the proportion of lodgepole pine infected with *A. mellea* that was attacked by the mountain pine beetle and to determine whether the infections were of a saprophytic or parasitic nature. This report documents the first record of an association between the mountain pine beetle and the root disease caused by *A. mellea* in lodgepole pine.

Although root pathogens have been implicated repeatedly as important biotic agents responsible for predisposing conifers to bark beetle attack, definitive evidence documenting the extent of their involvement has been difficult to obtain (Cobb and others 1974). Understandably, the time and effort required to excavate root systems to document the incidence and severity of these rots have slowed efforts to gain a meaningful understanding of their role in the dynamics of bark beetle populations.

Armillaria mellea infection causes butt rot, growth reduction, and perhaps eventual death of the infected tree (Morrison 1981). Some suspect that *A. mellea* is the most common root pathogen infecting lodgepole pine (Krebill 1975). In northern Idaho, this pathogen caused a high percentage of the rot in roots of western white pine (*Pinus monticola* Dougl.) but was not thought to increase the probability of attack by the mountain pine beetle (Ehrlich 1939). However, Kulhavy and others (1984) excavated entire root systems of white pine (*Pinus monticola* Dougl.) with explosives and found a strong association between the presence of *A. mellea* and MPB. They postulated that establishment of *A. mellea* is aided by infection from another pathogen, blister rust (*Cronartium ribicola* Fisch.), that girdles the bole, causing a decline in host condition. *Armillaria mellea* was found infecting ponderosa pine (*Pinus ponderosa* Laws.) infested with several species of bark beetles in Idaho (Partridge and Miller 1972), California (Cobb and others 1974), Colorado (Fuller 1983), and New Mexico (Livingston and others 1983). In South Dakota, examination of the roots of 115 ponderosa pines killed or currently infested by MPB revealed a statistically significant association between beetle-killed trees and the presence of *A. mellea* (Hinds and others 1984). Examination of 16 lodgepole pine stands in central Idaho revealed that, although *A. mellea* was occasionally present in root systems within the study area, none of the trees examined were infested with bark beetles, including the mountain pine beetle (Kulhavy and others 1978). These results were in keeping with an earlier study that found the incidence of root diseases and infestation by MPB did not show a strong correlation in mature stands of lodgepole pine (Partridge and Miller 1972). In contrast, investigation of an apparent association between fire-scarred lodgepole pine and the fungus *Poria asiatica* (Pilat) Overholts in Oregon revealed that trees with advanced stages of thi disease were susceptible to attack by MPB (Geiszler a others 1980; Gara and others 1985).

STUDY AREA

The lodgepole pine stand in which the association wa discovered was on the North Slope of the Uinta Mountains, elevation 8,500 feet (2 600 m), approximate 22 miles (35 km) south of Mountain View, WY, on the Wasatch National Forest. The 90-acre (36-ha) stand covered had a mean age of 112 years, diameter at brea height (d.b.h.) of 6.8 inches (17.2 cm), and basal area of 48 ft^2 per acre (118 m^2 per ha). The community type is *Pinus contorta/Vaccinium scoparium* (Steele and other 1983). The area experienced major outbreaks of the mountain pine beetle in the 1930's and 1950's. Until summer 1982, MPB populations were considered endemic, but during summer 1983, three tree groups were infested, suggesting populations were building toward the outbreak phase common in stands east of study area.

METHODS

Twenty variable-radius plots (BAF 10) were established in the stand during October 1983 at 5-chain (100.6-m) intervals along two randomly located transe 10 chains (201.2 m) apart. On each plot, a maximum o three trees were examined for the presence of root dis eases. The trees were classified as live (not infested b MPB), currently infested (infested during mid-August 1983 by MPB), or dead (killed by MPB previous to 1983). Currently infested trees were examined within weeks of MPB attack; therefore, ratings of disease severity had not been affected by saprophytic spread. Eight additional trees infested by MPB in August 19 were examined in October 1984. The first tree of each category encountered in a clockwise rotation from tru north was selected for disease diagnosis. In addition, trees categorized as infested or dead, which were outs the survey transects but within the 90-acre (36-ha) st area, were also examined for the presence of root rot.

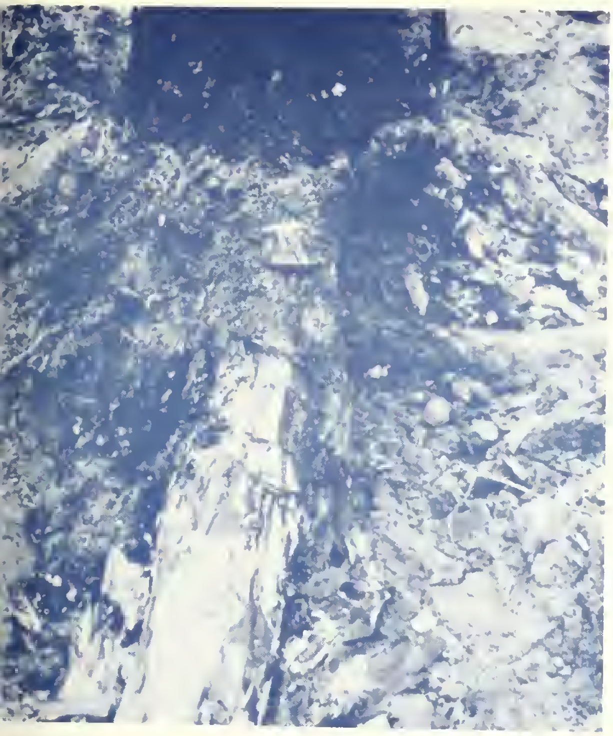
Roots of each tree were excavated out to 3 feet (0.9 from the bole and down to 1.5 feet (0.5 m) below grou line. The root collar was examined for evidence of res sis or mycelial fans of *A. mellea* (figs. 1, 2). Next, individual roots were examined for resin-encrusted lesions or subcortial mycelial fans with rhizomorphs, characteristic external indicators of *A. mellea* infectio (figs. 3, 4). The degree that primary roots were infect by *A. mellea* was rated by percentage as follows:

0	No apparent infection
1	1 to 25 percent
2	26 to 50 percent
3	51 to 75 percent
4	76 to 100 percent

Resinosis on the roots was considered an indicator of parasitic infection that was present prior to beetle infestation (Cobb and others 1974). Root sections fro

---

[3] AUTHORS' NOTE: Recent taxonomic and genetic studies have segregated several biological species in the *Armillaria mellea* complex (Wargo and Shaw 1985). Techniques for determining the biological species of diploid field isolates were not available when this study was completed. The isolates collected during this study will be paired with known haploid testers to determine their taxonomic position.



ure 1.—Lower bole and exca-
ed root collar of lodgepole pine
outer bark removed showing
elial fans of *A. mellea*.

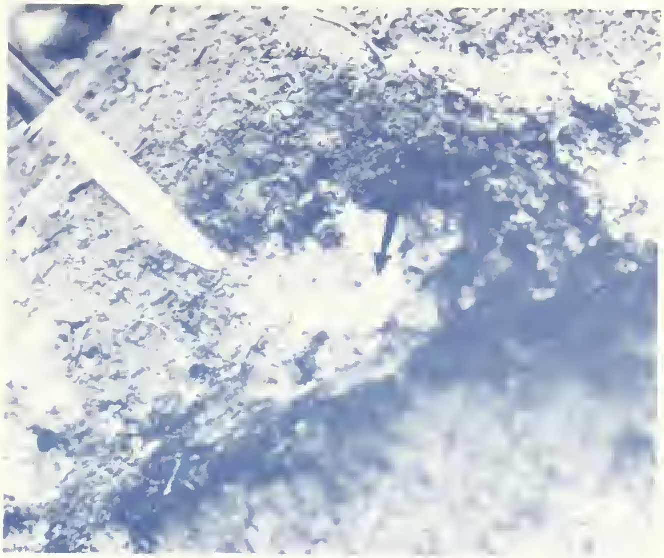


Figure 3.—Primary root showing resin-encrusted lesion common on many roots of trees infected with *A. mellea*.

e 2.—Lower bole of lodgepole pine with
bark removed to show *A. mellea*
lial mats immediately adjacent to
ries of the mountain pine beetle.

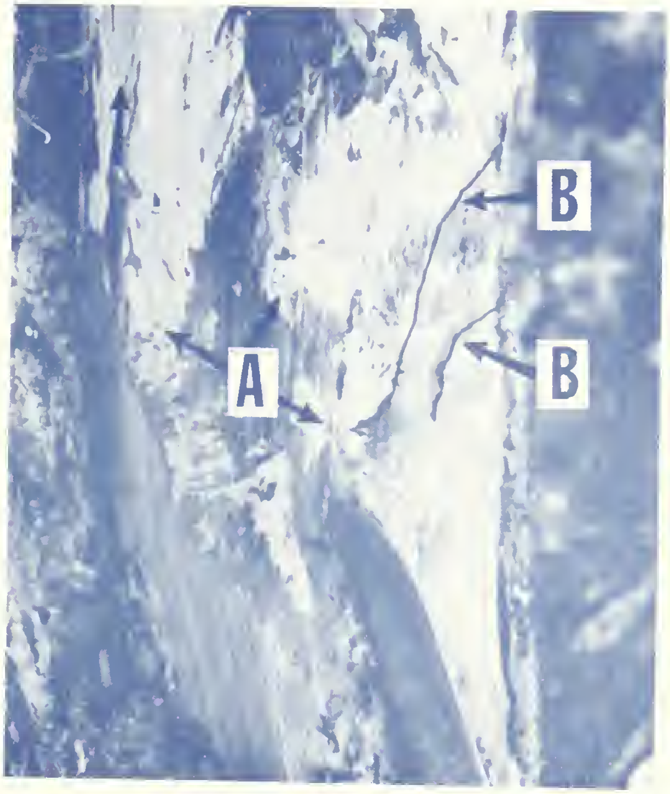


Figure 4.—Primary root with outer bark removed to show mycelial mat (A) and rhizomorph (B) of *A. mellea*.

each tree were transported to the laboratory for isolation of fungi. Wood chips from these roots were aseptically placed on 2 percent malt agar and incubated for 2 months at room temperature to encourage growth of fungi for identification (fig. 5). The root sections were also incubated for 6 months in moist sand to promote *A. mellea* rhizomorph growth (fig. 6).

All trees were also rated for severity of comandra rust (*Cronartium comandrae* Pk.) (Brown 1977) and dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) (Hawksworth 1977) infection.

Contingency tables were used to analyze the association of MPB infestation and mortality and disease incidence for trees sampled on the 20 variable plots. The associations were considered significant ($p \leq 0.05$) if c square values exceeded 5.99. Contingency tables were also constructed to analyze the following pest associations: dwarf mistletoe and MPB, comandra rust and MPB, dwarf mistletoe or comandra rust and MPB, dwarf mistletoe and *A. mellea*, comandra rust and *A. mellea*, dwarf mistletoe or comandra rust and *A. mellea*.

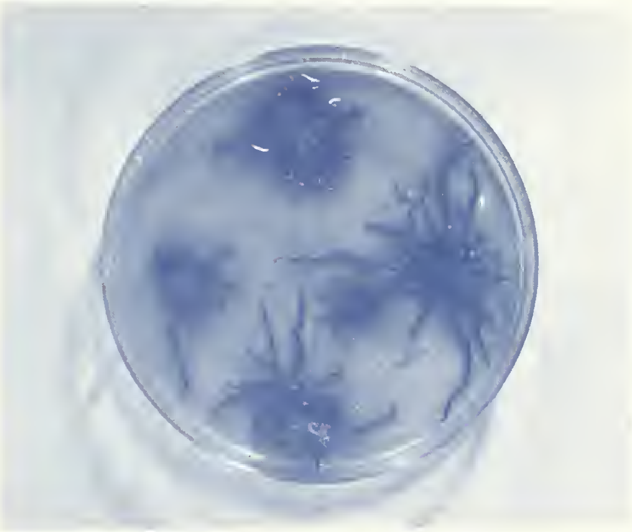


Figure 5.—Wood chips from root sections suspected of being infected with *A. mellea* were incubated in the laboratory to promote development of identifying characteristics such as rhizomorphs.

RESULTS

A total of 42 trees were examined on the 20 plots. C these, 20 were classified as live and uninfested, 12 as currently infested with beetles, and 10 as previously killed by beetles. *Armillaria mellea* was positively iden fied on two live uninfested trees, 11 currently infested trees, and eight dead trees (table 1). This includes onl those trees that had external indicators of parasitic *A. mellea* infection or yielded *A. mellea* in culture. Of trees with the visual indicators of parasitic *A. mellea* infection, 19 were infested by MPB, while only three

Table 1.—Contingency table comparing the number of trees infested by mountain pine beetle (MPB) with the presence of parasitic *Armillaria mellea* (AM) infection in a selected lodgepole pine stand, Wasatch National Forest, UT, 1983-1984

	MPB infestation category			
A. mellea incidence	Live (not infested)	Currently infested	Dead	Subto
AM present[1]	2	11	8	21
AM absent	18	1	2	21
Subtotal	20	12	10	42
Chi-square value = 24.73				

---

[1] Presence determined by existence of external indicators of *A. mellea* mycelial fans on roots of host tree or by laboratory cultu yielding *A. mellea* isolates.

Figure 6.—Primary root showing *A. mellea* rhizomorphs that developed from lesions after incubation in moist sand.

Table 2.—Comparison of the number of trees infested by the mountain pine beetle (MPB) with the severity of *A. mellea* (AM) infection ratings in primary roots of lodgepole pine, Wasatch National Forest, UT, 1983-1984

MPB infestation category	Severity of primary root infection by *A. mellea*[1]					
	0	1	2	3	4	Subtotal
Live (not infested)	18	0	1	1	0	20
Currently infested	9	9	12	6	3	39
Dead	2	2	0	1	9	14
Subtotal	29	11	13	8	12	73

[1] Rating based on percentage of primary roots infected with *A. mellea*:
- 0 No apparent infection (as indicated by absence of *A. mellea* signs or failure to culture pathogens)
- 1 1 to 25 percent of primary roots infected
- 2 26 to 50 percent
- 3 51 to 75 percent
- 4 76 to 100 percent.

21 trees with no visible *A. mellea* indicators were nfested (table 1). The chi-square value for the association in table 1 is 24.73, which indicates that the associations are significant at the $p \leq 0.05$ level. Analysis of the association of comandra rust and dwarf mistletoe with *A. mellea* and MPB revealed that none of the associations were significant at the $p \leq 0.05$ level.

Table 2 gives root disease ratings for all 73 trees examined (42 on variable plots and 31 in beetle-infested areas). Live trees (unattacked) tended to have lower severity of infection ratings than trees currently infested or killed previously by the beetle. The higher ratings for dead trees probably resulted from saprophytic spread of *A. mellea* following the death of the host tree as reported earlier by Ehrlich (1939).

All of the beetle-killed and infested trees exhibited some resinous lesions on the roots, indicating infection by *A. mellea* was present prior to beetle attack. No other root disease fungus was identified. Several trees yielded unidentified imperfect fungi. These isolates are being examined further to determine if they are associated with root diseases or stains.

DISCUSSION

This initial survey revealed that mature lodgepole pine infected with *A. mellea* were infested by endemic population levels of the mountain pine beetle with greater frequency than uninfected lodgepole pine (table 1). The results emphasize the need to determine the mechanism by which those host trees are located. Although this study was not designed to determine the host selection mechanism, several explanations for such associations have been formulated by those studying other bark beetle-root rot associations (Cobb and others 1974; Hertert and others 1975; Alexander and others 1981).

Basically, two hypotheses have been developed to explain the associations between *A. mellea*-infected ponderosa pine and bark beetles. The most frequently proposed explanation is based on the premise that bark beetles attack trees at random (Vité and Wood 1961; Wood 1972), and that the presence of disease—particularly root rot—reduces a tree's resistance to beetle attack. Those supporting this hypothesis reason that water uptake is restricted, thereby limiting wound response in the form of resin exudation (Rudinsky 1962; Shrimpton 1978). Because *A. mellea* is a root pathogen that kills the phloem and decays the stem, it likely interferes with water absorption, resulting in a moisture deficit similar to that caused by drought. However, we do not know the degree of root infection and resultant moisture stress needed to reduce resin exudation below the threshold that permits successful attack by endemic populations. Attempts to simulate drought stress by freezing the root collars of ponderosa pine to disrupt water uptake did not significantly increase the landing rate of the mountain pine beetle on the treated trees compared to the untreated controls (Moeck and others 1981).

A second hypothesis is based on the premise that diseased trees are more attractive to dispersing beetles than are uninfected trees. Geiszler and others (1980) found that during the first few years of an outbreak, more fire-scarred lodgepole pines than unscarred were killed by MPB . More recently, measures of MPB host-selection behavior revealed that dispersing beetles preferentially select fire-scarred trees, primarily those infected by *P. asiatica* (Gara and others 1984). In contrast, field experiments by Moeck and others (1981) that were designed to determine whether pioneer beetles detect diseased hosts by olfaction, revealed no significant difference in landing rates of the mountain pine beetle on ponderosa pine infected with the root pathogen *Verticicladiella wageneri* Kendrick. The researchers concluded there was no evidence that trees infected with root disease produced primary attractants that guided inflight populations to these trees. More recently, Conn and others (1984), studying the quantity of pheromone production by axenically reared *D. ponderosae*, revealed that these microorganism-free beetles produce six times more **trans**-verbenol than wild beetles infected with associated microorganisms. These researchers also concluded that wild beetles produce less **trans**-verbenol because the internal microorganisms present either inhibit production of this pheromone or use it as a substrate that is converted to other compounds.

Additional tests and bioassays are needed to determine if such microorganisms play a role in primary attraction as suggested by Geiszler and others (1980).

Data presented here do not favor either of the host-selection hypotheses but do document an association between the mountain pine beetle and host trees infected with root rot. This association appears to be an important factor affecting the dynamics of endemic level populations. Within the 20 plots, the endemic populations present tended to concentrate on trees infected with *A. mellea*. Regardless of the host selection mechanism, the need to concentrate scattered populations on suitable hosts during the endemic period is essential to ensure mating and overcoming host resistance. While diseased trees likely have a reduced wound response favoring successful attack, they also tend to grow more slowly, resulting in thin phloem (Cole 1973). Thin phloem reduces brood survival, offsetting the increased brood survival likely to result from reduced wound response (Amman 1969; Cole and Amman 1969).

To determine the importance of this bark beetle—root rot association to the dynamics of low population levels, there is need to determine the incidence of *A. mellea* by habitat type within the lodgepole pine type and the frequency with which such trees are infested by endemic populations. Although, the association between comandra rust or dwarf mistletoe or both, and *A. mellea* was not significant, we suspect the high incidence of these two stem diseases in the stand may contribute to the spread of *A. mellea*. Accordingly, there is need to evaluate the interactions of these pathogens. There is also need to measure brood survival in the infected trees. Studies under way address these needs and seek to determine if the association serves as a triggering mechanism that allows endemic populations to reach outbreak status.

REFERENCES

Alexander, S. A.; Skelly, J. M.; Webb, R. S. Effects of *Heterobasidion annosum* on radial growth in southern pine beetle-infested loblolly pine. Phytopathology. 71: 479-481; 1981.

Amman, G. D. The biology, ecology, and causes of outbreaks of the mountain pine beetle in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 39-53.

Amman, G. D. Mountain pine beetle emergence in relation to depth of lodgepole pine bark. Research Note INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 8 p.

Amman, G. D.; Baker, B. H. Mountain pine beetle influence on lodgepole pine stand structure. Journal of Forestry. 70: 204-209; 1972.

Brown, D. H. Management guidelines for lodgepole pine stands infected with comandra blister rust and dwarf mistletoe. Technical Report R2-9. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Forest Insect and Disease Management, Rocky Mountain Region; 1977. 21 p.

Cobb, F. W., Jr.; Parmeter, J. R., Jr.; Wood, D. L.; Stark, R. W. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. In: Kuhlman, E. G., ed. Proceedings of the fourth international conference on *Fomes annosus*; 1973 September 17-22; Athens, GA. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1974: 8-15.

Cole, D. M. Estimation of phloem thickness in lodgepole pine. Research Paper INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 10 p.

Cole, W. E. Problem analysis: population dynamics of the mountain pine beetle. 1979. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 22 p.

Cole, W. E.; Amman, G. D. Mountain pine beetle infestations in relation to lodgepole pine diameters. Research Note INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 7 p.

Conn, J. E.; Borden, J. H.; Hunt, D. W. A.; Holman, J.; Whitney, H. S.; Spanier, O. J.; Pierce, H. D., Jr.; Oehlschlager, A. C. Pheromone production by axenically reared *Dendroctonus ponderosae* and *Ips paraconfusus* (Coleoptera: Scolytidae). Journal of Chemical Ecology. 10: 281-290; 1984.

Ehrlich, J. A preliminary study of root diseases in western white pine. Station Paper No. 1. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Rocky Mountain Forest and Range Experiment Station; 1939. 11 p.

Fuller, L. R. Incidence of root diseases and dwarf mistletoe in mountain pine beetle killed ponderosa pine in the Colorado Front Range. Biological Evaluation R2-83-2. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1983. 8 p.

Gara, R. I.; Geiszler, D. R.; Littke, W. R. Primary attraction of the mountain pine beetle to lodgepole pine in Oregon. Annals of Entomological Society of America. 77: 333-334; 1984.

Gara, R. I.; Littke, W. R.; Agee, J. K.; Geiszler, D. R.; Stuart, J. D.; Driver, C. H. Influence of fires, fungi and mountain pine beetles on development of a lodgepole pine forest in south-central Oregon. In: Baumgartner, David M.; Krebill, Richard G.; Arnott, James T.; Weetman, Gordon F., eds. Lodgepole pine, the species and its management: symposium proceedings; 1984 May 8-10; Spokane, WA. Pullman, WA: Washington State University Cooperative Extension; 1985: 153-162.

Geiszler, D. R.; Gara, R. I.; Driver, C. H.; Gallucci, V. F.; Martin, R. E. Fire, fungi and beetle influences on a lodgepole pine ecosystem of southcentral Oregon. Oecologia (Berl.). 46: 239-243; 1980.

Hawksworth, F. G. The 6-class dwarf mistletoe rating system. General Technical Report RM-48. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 7 p.

Hertert, H. D.; Miller, D. L.; Partridge, A. D. Interaction of bark beetles (Coleoptera: Scolytidae) and root-rot pathogens in grand fir in northern Idaho. Canadian Entomologist. 107: 899-904; 1975.

Hinds, T. E.; Fuller, L. R.; Lessard, E. D.; Johnson, D. W. Mountain pine beetle infestation and *Armillaria* root disease of ponderosa pine in the Black Hills of South Dakota. Technical Report R2-30. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; 1984. 16 p.

Krebill, R. G. Lodgepole pine's fungus-caused diseases and decays. In: Baumgartner, D. M., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 377-405.

Kulhavy, D. L.; Partridge, A. D.; Stark, R. W. Mountain pine beetle and disease management in lodgepole pine stands: inseparable. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 177-181.

Kulhavy, D. L.; Partridge, A. D.; Stark, R. W. Root diseases and blister rust associated with bark beetles (Coleoptera: Scolytidae) in western white pine in Idaho. Environmental Entomology. 13: 813-817; 1984.

Livingston, W. U.; Mangini, A. C.; Kinzer, U. G.; Mielke, M. E. Association of root diseases and bark beetles (Coleoptera: Scolytidae) with *Pinus ponderosa* in New Mexico. Plant Disease. 67: 674-676; 1983.

Moeck, H. A.; Wood, D. L.; Lindohl, K. Q., Jr. Host selection behavior of bark beetles (Coleoptera: Scolytidae) attacking *Pinus ponderosa* with special emphasis on the western pine beetle, *Dendroctonus brevicomis*. Journal of Chemical Ecology. 7: 49-83; 1981.

Morrison, D. J. *Armillaria* root disease: a guide to disease diagnosis, development and management in British Columbia. BC-X-203. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre; 1981. 15 p.

Partridge, A. D.; Miller, D. L. Bark beetles and root rots related in Idaho conifers. Plant Disease Reporter. 56: 498-500; 1972.

Rudinsky, J. A. Ecology of Scolytidae. In: Steinhaus, Edward A.; Smith, Ray F., eds. Annual Review of Entomology. 7: 327-348; 1962.

Shrimpton, D. M. Resistance of lodgepole pine to mountain pine beetle infestation. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 64-76.

Steele, R.; Cooper, S. V.; Ondov, D. M.; Roberts, D. W.; Pfister, R. D. Forest habitat types of eastern Idaho-western Wyoming. General Technical Report INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 122 p.

Thier, R.; Hoffman, J. Forest insect and disease conditions: Intermountain Region, 1982. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region; 1982. 23 p.

U.S. Department of Agriculture, Forest Service. Executive summary: lodgepole pine/mountain pine beetle situation United States/Canada, 1981. Washington, DC: U.S. Department of Agriculture, Forest Service; 1983. 16 p.

Vité, J. P.; Wood, D. L. A study on the applicability of the measurement of oleoresin exudation pressure in determining susceptibility of second growth ponderosa pine to bark beetle infestation. Contributions of Boyce Thompson Institute of Plant Research. 21: 67-78; 1961.

Wargo, P. M.; Shaw, C. G. III. *Armillaria* root rot; the puzzle is being solved. Plant Disease. 69:326-823; 1985.

Wood, D. L. Selection and colonization of ponderosa pine by bark beetles. In: vanEmdem, H. F., ed. Insect/plant relationships: symposium proceedings; Royal Entomological Society, London. London: Blackwell; 6: 101-117; 1972.

*U.S. GOVERNMENT PRINTING OFFICE: 1985-0-676-039/20.031

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

ed States
artment of
culture

est Service

rmountain
earch Station
len, UT 84401

earch Note
354

uary 1986

Susceptibility of Pine Populations to Western Gall Rust—Central Idaho

R. J. Hoff[1]

3STRACT

)ifferences among provenances of ponderosa pine : observed in response to infection by western gall . The average level of resistance was 21 percent and ed from 5 to 45 percent. Differences appeared to vary andom within the geographic study area. Several : responses were visible, and these are discussed in is of their possible role as defense mechanisms.

YWORDS: western gall rust, host responses, provenances

ıst fungi are among the most destructive pathogens ıltivated plants. Nearly every agronomic breeding ;ram includes resistance to one or more rusts. With- continued vigilance to maintain, improve, or develop rust-resistant varieties, crop losses would be ıibitive.

ost, if not all, of the pines of the world are suscepti- .o one or several rust fungi of the genera *ıartium*, *Endocronartium*, or *Peridermium*. In situa- :s where the host trees grow naturally, destruction by ıe fungi is minimal and economically unimportant. as in agronomic crops, tree cultivation causes a ırbance of natural ecosystems which alters the ıtat and in many cases causes an increase in damage ree rusts. The classic case in forestry is the *:artium fusiforme:Pinus taeda*, *Pinus elliottii* interac- that has caused serious losses (Siggers and gren 1947). Fusiform rust resistance has become an ortant and expensive requirement in intensive agement programs of these important timber ies.

Western gall rust caused by *Endocronartium harknessii* is potentially a serious disease of many pines throughout most of North America (Peterson 1967). Two important timber species in the Northern Rockies, lodgepole pine (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*), are susceptible to this rust. Presently, western gall rust-caused damage, aside from localized stands, is mainly a management concern in plantations and seed orchards (Martinsson 1980). Some practices associated with intensive forest management, like replanting, are likely to result in an increase in this disease. It is imperative, therefore, to secure knowledge about the biological dynamics of these rust:pine systems before the natural environment is badly disturbed. Knowledge of the kinds and levels of host responses relative to locations of the provenances, and how the rust varies with provenance and pine host, would aid the forest manager in the transfer of seed and in the selection of better timber types.

Variation among provenances, together with some information on host responses, has been reported for both lodgepole and ponderosa pine (Martinsson 1980; Thomas and Hart 1983). In addition, host responses on various pines infected by western gall rust have been reported (Hutchinson 1935; York 1938; Nelson 1972; Hiratsuka and Maruyama 1983). This paper reports on variation among populations of ponderosa pine from central Idaho in response to artificial inoculation by western gall rust.

MATERIALS AND METHODS

Seeds from 39 populations from central Idaho (fig. 1, table 1) were sown in 10-in^3 containers in May of 1981. The seedlings were grown and overwintered in a shadehouse at the Forestry Sciences Laboratory, Moscow, ID. During the summer, the seedlings were watered and lightly fertilized with the objective of producing seedlings that are not stressed but without accelerating their growth. During the winter, the seedlings were set on the ground within a screened cage to protect them from large accumulations of ice and snow. Bases were surrounded with sawdust so the roots would not freeze.

---

[1]ri pal plant geneticist located at Intermountain Station's
or ry Sciences Laboratory, Moscow, ID.

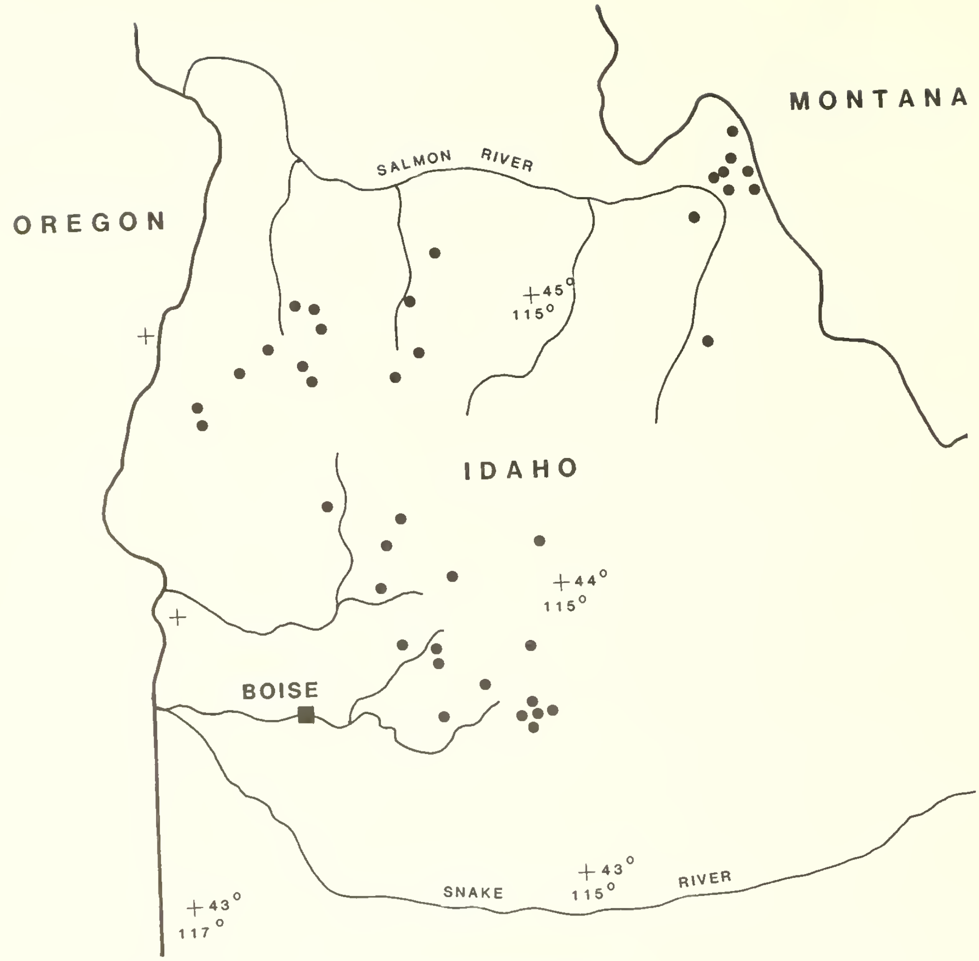


Figure 1.—Location of populations of ponderosa pine included in this test.

The following spring, the seedlings were put back on benches in the shadehouse. In May of 1982, when the needles were just beginning to break out of the fascicle sheaths, the seedlings were moved into a mist chamber in preparation for inoculation. Mist nozzles operated so that a fog was constantly visible throughout the chamber. Twenty-four hours later, the stems of the seedlings were wet down and allowed to set for 1 hour to remove excess moisture. At this point, the seedlings were ready to inoculate.

Experimental design:
  39 provenances
    3 replications
    7 seedlings/replication

Sixty-three seedlings randomly selected from all provenances served as uninoculated comparison trees.

Fresh inoculum was collected from at least 50 galls from a young lodgepole pine stand located in the Moose Creek drainage (lat. 46°51′ N., long. 116°23′ W., elevation 2,900 ft) about 3 miles west of Bovill, ID. Inoculation was accomplished by blowing spores over the seedlings using an air-sprayer adapted from an Erlenmeyer flask. Each replication was inoculated separately with a mixture of 355 mg of aeciospores an 2 g of talc. This gave a spore-to-seedling ratio of abou 30,000 to 1. The seedlings were maintained in the mis chamber for 72 hours, again with a constant, visible f The mist nozzles were then turned off and the seedlin allowed to slowly dry. When dry, the seedlings were moved back to the shadehouse. Frequent inspections signs of rust infection were made throughout the summer. Data concerning presence of galls and bark reactions were taken each spring and fall.

In September, the seedlings were moved to Priest River Experimental Forest and planted at a spacing 6 by 6 inches. The seven seedlings from each populat per replication were planted in row plots. The compar son trees (three rows of seven trees per replication) w evenly spaced within the replication.

Analysis of variance and the associations of geographic patterns with infection were completed us SAS programs (SAS 1982). Provenance means (perce nongalled) were transformed to arcsin $\sqrt{\text{percent}}$ (Stee and Torrie 1960). Values of 0 percent or 100 percent were assigned values of ¼n and 100 − ¼n, respecti (Steel and Torrie 1960).

able 1.—Location and host responses of seedlings of ponderosa pine inoculated with western gall rust

				Non-galled				Galls present			
tand	Elevation	Latitude	Longitude	No symptoms	Red spots and streaks	Necrotic tissue	Total	Rate[1] of appearance	Number[2]	Dead[3] rust	Total infected
	Feet	*°N.*	*°W.*			*Percent*				*Percent*	
1	6,000	44 – 57	114 – 20	10	5	5	19	34	2.4	24	51
2	4,400	45 – 30	113 – 55	0	14	19	33	72	2.5	43	67
3	6,150	45 – 30	114 – 10	5	0	5	10	40	3.7	47	90
4	5,720	45 – 27	114 – 13	5	20	0	25	32	3.2	53	75
5	5,400	45 – 27	114 – 13	0	5	10	15	84	3.3	35	85
6	4,680	45 – 25	114 – 11	0	14	10	24	62	3.7	56	76
7	4,700	43 – 51	115 – 53	5	6	11	11	68	3.2	75	89
8	5,200	44 – 19	116 – 14	0	5	24	29	67	2.9	53	71
9	6,000	44 – 47	115 – 52	5	19	5	29	68	3.2	40	71
10	4,100	44 – 40	116 – 52	0	29	14	43	91	3.1	33	57
11	6,000	43 – 48	115 – 43	0	5	24	29	73	2.6	27	71
12	4,400	45 – 03	116 – 23	5	2	7	14	55	3.2	17	86
13	3,700	44 – 54	116 – 29	0	0	5	5	61	3.3	22	95
14	4,200	45 – 03	116 – 16	0	10	5	15	44	2.8	59	85
15	4,400	44 – 59	116 – 13	0	0	5	5	44	4.1	50	95
16	5,500	43 – 44	115 – 27	5	13	0	18	63	3.2	52	82
17	4,000	44 – 18	115 – 52	5	5	20	30	73	2.7	43	70
18	3,100	44 – 04	115 – 56	0	0	5	5	43	3.2	42	95
19	4,300	44 – 53	115 – 42	5	15	25	45	64	2.5	45	55
20	4,800	45 – 07	115 – 45	0	15	7	22	77	3.2	43	78
21	5,800	43 – 37	115 – 17	0	0	5	5	80	3.7	50	95
22	4,300	43 – 37	115 – 43	0	14	19	33	39	3.5	57	67
23	4,100	43 – 50	115 – 43	0	5	0	5	36	3.1	50	95
24	4,400	43 – 50	115 – 22	10	18	10	38	62	2.6	46	62
25	5,100	44 – 11	115 – 13	5	5	0	10	37	3.7	47	90
26	4,100	44 – 07	115 – 37	0	9	5	14	90	2.6	50	86
27	3,400	44 – 13	115 – 50	0	14	0	14	37	3.1	56	86
28	4,600	44 – 55	116 – 40	0	5	19	24	41	2.5	31	76
29	5,800	44 – 42	116 – 40	0	19	14	33	76	3.7	64	67
30	4,700	44 – 48	116 – 17	5	5	0	10	65	3.0	26	90
31	6,200	45 – 15	115 – 37	0	9	5	14	56	4.3	33	86
32	4,700	43 – 37	115 – 14	0	5	20	25	72	2.6	53	75
33	4,600	43 – 37	115 – 13	5	11	5	21	36	3.1	73	79
34	4,600	43 – 35	115 – 14	0	5	5	10	44	3.6	67	90
35	5,000	43 – 36	115 – 04	0	0	14	14	33	3.8	11	86
36	5,300	44 – 48	116 – 17	0	9	5	14	61	3.3	22	86
37	5,600	45 – 19	114 – 20	5	4	10	19	50	3.7	41	81
38	5,600	45 – 38	114 – 00	5	27	11	43	62	3.5	38	57
39	5,900	47 – 27	113 – 58	0	9	24	33	62	3.2	43	67
Average				2	9	10	21	58	3.2	44	79

[1] Ratio of galls appearing at 4 months to 28 months after inoculation.

[2] Galls per infected seedlings.

[3] Infected seedlings that died.

RESULTS

Several host reactions were observed.

1. Red spots, streaks, and blotches on stems within a month of inoculation.

2. Small dead patches on the stems within 2 months of inoculation (fig. 2).

3. Small swellings and bumps indicating incipient galls within 4 months of inoculation (fig. 3).

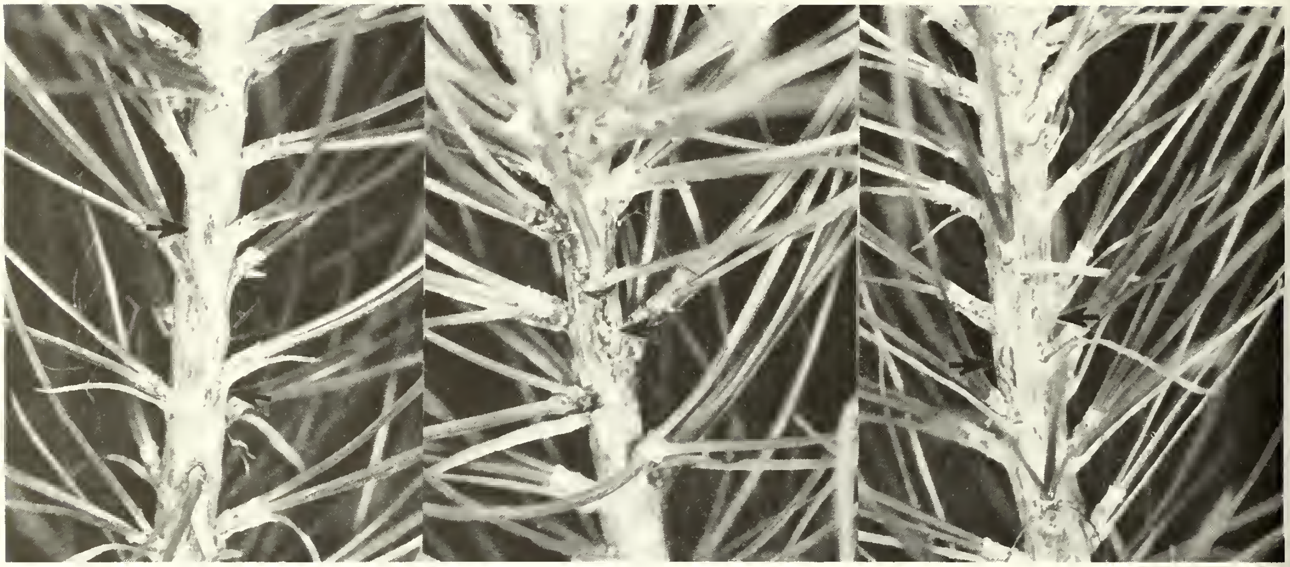


Figure 2.—Small necrotic areas (arrows) on the stems of ponderosa pines 2 months after inoculation with western gall rust.

Figure 3.—Incipient galls of western gall rust on seedlings of ponderosa pine 4 months after inoculation.

4. Large, dead patches on the stem that increased in size from 4 to 28 months after inoculation (fig. 4). Some of these reactions were so severe that they caused malformation of the seedling (fig. 5).

5. Collapse and death of galls.

6. Variation in size of galls (fig. 6).

Out of 819 trees inoculated, only 17 had no symptoms (table 1). None of the 98 control seedlings had symptoms.

Figure 4.—Large necrotic areas on the stems of ponderosa pines 4 to 12 months after inoculation.

Figure 5.—Malformed seedling caused by many bark reactions.

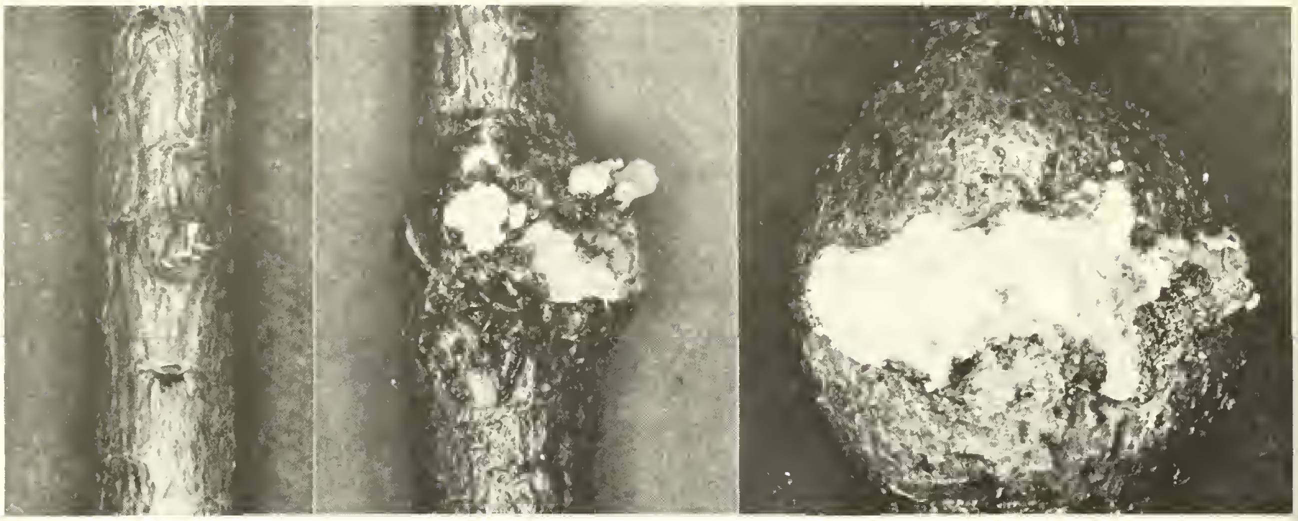


Figure 6.—Variation in size of galls of western gall rust on ponderosa pines.

The percentage of seedlings without galls (that is, with evidence of resistance) was 21 percent. This ranged from 5 to 45 percent among populations (table 1). These means were significantly different at the 2 percent level (table 2).

Of the nongalled seedlings, 10 percent (2 percent verall) had no symptoms; 42 percent (9 percent overall) exhibited red spots, streaks, or blotches on the stem; and 48 percent (10 percent overall) had dead patches of various sizes on the stem, or had developed a gall (table 1).

The percentages of nongalled seedlings by population were plotted against elevation, latitude, and longitude. The R^2 values were 0.02, 0.03, and 0.01, respectively. The percentages of nongalled appear to be random (table 1) for these factors.

Table 2.—Analysis of variance of transformed means of seedlings without galls from 39 populations of ponderosa pine

	Degrees of freedom	Mean square	F	Probability >F
Block	2	0.121	2.95	0.057
Population	38	.072	1.76	.017
Block × population	76	.041		

Fifty-eight percent of the galls that were present at 28 months first appeared at 4 months (table 1). This varied among the populations from 32 to 91 percent. Probability of a higher F value for differences among the population means was 0.15. And the R^2 values for elevation, latitude, and longitude were essentially zero.

The percentage of infected trees in the population that had died by 28 months after inoculation averaged 44 percent, ranging from 11 to 73 percent (table 1). Probability of a higher F value was 0.23, and there were no associations with elevation, latitude, or longitude.

DISCUSSION

It is rare to find natural stands of ponderosa pine severely damaged by western gall rust in the Northern Rocky Mountains. And yet, in this test, 79 percent of the seedlings were infected, and nearly half of those we dead within 28 months after inoculation. The cause was probably the high spore density applied under optimal conditions—a situation not likely to occur very often in nature. Rust infection most frequently occurs in wave years (Leaphart 1955; Peterson 1959). Years that are foggy with intermittent showers during the high spore production time would seem to be ideal.

High resistance does not seem to be necessary in maintaining natural balance with this host-pest system. The probability of high spore density, coupled with optimal environmental conditions, may be quite low. In working out an artificial inoculation procedure, I found that a visible fog was not enough. I had to make sure the stems of the seedlings were wet. This method provided just the right conditions. These conditions ma not occur in nature very often.

Even though the total level of resistance was only 21 percent, the rich assortment of host responses suggests that there are several defense mechanisms an consequently, many genes involved.

Signs of Defense Mechanisms

1. No symptoms: Infection was so high that it is har to believe that these seedlings had escaped infection. Resistance could be due to prevention of spore germination, formation of an effective barrier by the cuticle or epidermal cell walls, or destruction of the penetrating germ tube, which results in a very small host sign not readily visible.

2. Red spots, streaks, or blotches with no visible sig of necrotic stem patches or gall symptoms: This reactio was not severe enough to cause a visible necrotic patch on the stem, so presumably the fungus was either prevented from entering because the chemicals causing

d coloration in that seedling possibly were toxic, or the ngus was destroyed soon after penetration, but the fense reaction was so severe or quick that no necrosis as observed.

3. Necrotic patches on the stem: These ranged from ry small patches that would soon be overgrown or oughed off, to very large patches, at times so severe at they caused seedlings to be malformed.

Hutchinson (1935) reported similar reactions in *Pinus lvestris* infected with western gall rust. He found that e first type was a fairly quick response by the host at killed the fungus, but the more severe reactions ere often typified as a seesaw reaction by host and ngus: the host produced a wound periderm, then the ngus broke through, then the host would produce nother periderm, and so on, until either the host or the ngus succumbed, or they both lived in some kind of a ysiological balance.

4. Gall death: This may just be an extension of the vere stem reactions. But in these cases, there were no rly signs of a resistant host reaction.

5. Gall size: The galls in some seedlings were so small at very little damage would be expected.

6. Rate of gall appearance: Although this trait was nsignificant in this provenance test, I expect that a mily test may show that this is an important defense echanism. Slow appearance and slow growth of the ngus would not likely result in causing much damage the host.

7. Tolerance: This is the ability of infected seedlings remain alive and, especially, to grow normally or close normal. Again, this trait was nonsignificant in this rovenance test.

Population differentiation appeared to vary randomly ver the landscape. But because the degree of resistance usually thought of as being a result of disease everity (Leppik 1970), why would geographically close tands have such large differences in resistance? One ause could be the varying and random probability of fection during regeneration; that is, conditions for oculation appear quite demanding, so the probability f optimal conditions occurring when trees are most vulnerable to infection and damage (when young) are small. A test of individual families with varying levels of spore density using rust collections from several sources now seems extremely valuable.

REFERENCES

Hiratsuka, Y.; Maruyama, P. Resistant reactions of two Asian pines to western gall rust, *Endocronartium harknessii*. Phytopathology. 73: 835; 1983. Abstract.

Hutchinson, W. G. Resistance of *Pinus sylvestris* to a gall-forming peridermium. Phytopathology. 25: 819-843; 1935.

Leaphart, C. D. Preliminary observations on a current outbreak of western gall rust (*Cronartium coleosporioides*). Plant Disease. 39: 314-315; 1955.

Leppik, E. E. Gene centers of plants as sources of disease resistance. Annual Review of Phytopathology. 8: 323-344; 1970.

Martinsson, O. Stem rusts in lodgepole pine provenance trials. Silvae Genetica. 29: 23-26; 1980.

Nelson, D. K. The ecology and pathology of pine gall rust in California. Berkeley: University of California; 1972. 160 p. Ph.D. dissertation.

Peterson, R. S. Geographic patterns in gall-rust infestation. In: Proceedings, 7th western intermountain forest disease work conference; Pullman, WA. 1959: 48-51.

Peterson, R. S. The peridermium species on pine stems. Bulletin of the Torrey Botanical Club. 94: 511-542; 1967.

SAS Institute. SAS user's guide: statistics. Cary, NC: SAS Institute; 1982. 584 p.

Siggers, P. V.; Lindren, R. M. An old disease—a new problem. Southern Lumberman. 175: 2201; 1947.

Steel, R. G. D.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Thomas, C. S.; Hart, J. H. Severity of *Endocronartium harknessii* on *Pinus ponderosa*. Phytopathology 73: 838; 1983. Abstract.

York, H. H. Inoculation of trees with rusts. Phytopathology. 28: 210-212; 1938.

*U.S. GOVERNMENT PRINTING OFFICE: 1986-0-676-039/20036

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station
Ogden, UT 84401**

Research Note
INT-355

March 1986

Performance of Douglas-fir Intervarietal Hybrids After 10 years of Field Testing

G. E. Rehfeldt[1]

ABSTRACT

After 10 years of field testing, Douglas-fir intervarietal hybrids have equaled the survival of inland parental lines, but doubled their height. Both hybrids and inland lines surpassed the survival and height of coastal parental lines. The performance of hybrid families seemed to reflect specific rather than general combining abilities, and variation within hybrid families was high.

KEYWORDS: *Pseudotsuga menziesii*, progeny tests, interprovenance hybridization

Hybridization offers the possibility of combining the growth potential of the coastal variety of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) with the winter hardiness of the inland variety (*Pseudotsuga menziesii* var. *glauca*). Such hybrids would increase the productivity of the inland variety while maintaining adaptation to severe environments. In an assessment of this possibility, Rehfeldt (1977) analyzed traits reflecting growth potential, morphology, phenology, and freezing tolerance of 4-year-old hybrid families. For all traits, hybrids were intermediate between parental lines, but freezing tolerance was more similar to that of the inland line than to that of the coastal line.

In the present paper, the performance of intervarietal hybrids is assessed after 10 years of field testing. Whereas an earlier report (Rehfeldt 1977) concerned genetic variation in single traits, this report assesses performance, the integration of numerous traits that produce the phenotype on a given site.

METHODS

As described previously (Rehfeldt 1977), hybrids had been developed on 20 maternal trees from two inland provenances by using pollen from 25 coastal trees representing four provenances (table 1). Each parental tree also was represented in the test by seedlings derived from wind pollinations in their native stands. Seedlings were grown for 3 years (1-2) at a nursery on the Priest River Experimental Forest where September frosts heavily screened all coastal lines and some hybrid

Table 1.—Survival and height of hybrids according to parental provenance

Provenance	Crosses	Survival	Height
	No.	*Percent*	*Ft*
Paternal parent			
Valsetz, OR, 1,150 ft, Coastal Range	21	54	7.1
Lacomb, OR, 850 ft, Cascade Range	40	65	7.5
Lyons, OR, 1,600 ft, Cascade Range	10	54	7.5
Cowichan Lake, BC, 600 ft, Vancouver Island	20	56	7.6
Maternal parent			
Moscow, ID, 2,700 ft	46	52	7.4
Clarkia, ID, 3,400 ft	45	65	7.3

---

[1] Plant geneticist at Intermountain Research Station's Forestry Sciences Laboratory, Moscow, ID.

families for tolerance to early autumn frosts. The survivors, representing 91 full-sib hybrid families and most parental lines, were planted in 1975 in row plots on a site at 3,400 feet elevation near Grangeville (lat. 46°, long. 116°) in northern Idaho.

Families were represented by one to four row plots with five to 10 seedlings within each plot. Plots were arranged at random within the plantation. There were 10 feet between rows and a minimum of 3 feet between seedlings within plots. Because of the mortality at the nursery, additional seedlings were grown in containers and were added to the plantation in 1976 as 1-year-old trees. Of the 3,900 trees planted, 25 percent were planted as 1-0 stock.

Thus, the planting contained an unequal number of crosses per parent, an unequal number of plots per cross, an unequal number of seedlings per plot, and an unequal age of planting stock. These imbalances preclude statistical analyses. Mean survival and height, recorded in 1984 after 10 years of field testing, are compared without regard to statistical probabilities.

RESULTS AND DISCUSSION

Of the planted trees, 55 percent were alive after 10 years of field testing. Survival of trees planted as 1-2 stock in 1975 averaged 59 percent while those planted as 1-0 stock in 1976 averaged 44 percent. Survival of hybrids averaged 58 percent, and for wind-pollinated inland parental lines, 63 percent. But survival for wind-pollinated coastal parental lines averaged only 20 percent.

The average tree was 5.7 feet tall. Trees planted in 1975 were about 2 feet taller than those planted in 1976. Hybrids averaged 7.3 feet, interior trees 4.2 feet, and coastal trees 3.4 feet. Standard deviations within plots averaged 2.5, 1.5, and 1.1 feet for hybrids, interior parental lines, and coastal parental lines, respectively.

The performance of individual hybrid families varied considerably (table 2). Survival ranged from 34 to 80 percent. Mean height ranged from 4.6 to 11 feet. The variation within families was also considerable. Standard deviations (table 2) indicate that two-thirds of the trees representing each family were within only 1.5 to 3 feet of the mean. In fact, the tallest tree (17 feet) came from a family in which 25 percent of the trees were shorter than 4 feet.

When the performance of hybrid families is summarized according to parental provenance (table 1), differences between means are small. It seems, therefore, that the provenance of the parent did not contribute to differential performance of hybrid families.

Indeed, the performance of a hybrid family depended on which specific trees were used as parents. No maternal tree from the interior produced hybrids of uniformly high levels of performance in several crosses. Likewise, no coastal tree produced uniformly superior hybrids. But hybrid families differed greatly and were highly variable (table 2).

Thus, after 10 years of field testing, hybrids equaled the survival of interior parental lines but were nearly twice as tall. However, the performance of a hybrid family could not be predicted from either the parental provenance or the specific parental tree. In addition, variance within families was high.

These results illustrate a high potential for hybridization to increase the productivity of inland Douglas-fir. Tree improvement, however, must proceed while maintaining adaptation to contemporary environments (Rehfeldt 1983). An expedient and safe means of utilizing hybridization in Douglas-fir breeding would involve selecting superior hybrid trees without regard to parentage, and then backcrossing these selected trees to a large number of interior trees. Superior individuals from families of stable performance should be suitable for producing clonal material for reforestation.

REFERENCES

Rehfeldt, G. E. Growth and cold hardiness of intervarietal hybrids of Douglas-fir. Applied Genetics. 50: 3-15; 1977.

Rehfeldt, G. E. Genetic variability within Douglas-fir populations: implications for tree improvement. Silvae Genetica. 32: 9-14; 1983.

Table 2.—Performance of full-sib hybrid families that represent the range of responses

Parental provenance		Total trees planted	Trees planted in 1975	Survival	Height	
Paternal	Maternal				Mean	Standard deviation
				Percent	----- *Feet* -----	
Cowichan Lake	Clarkia	35	35	45	4.6	2.4
Valsetz	Moscow	40	40	67	6.1	2.2
Lacomb	Moscow	41	37	89	7.1	2.6
Cowichan Lake	Clarkia	25	25	59	8.2	2.7
Lyons	Clarkia	32	32	34	8.8	2.0
Valsetz	Moscow	40	40	80	9.2	3.5
Lacomb	Moscow	42	36	53	10.0	2.7
Lacomb	Clarkia	15	15	53	11.1	1.7

United States
Department of
Agriculture

Forest Service

ntermountain
Research Station

Research Note
NT-356

July 1986

Distinguishing Mated and Unmated Mountain Pine Beetles in Alcohol-Preserved Specimens

Glen E. Trostle[1]

BSTRACT

Alcohol-preserved female mountain pine beetles from oth short-term and long-term storage were examined for vidence of insemination. The spermathecae of insemiated females were opaque, smooth, and rounded, while permathecae of unmated females were translucent, rainy, and wrinkled. The analysis shows that mated nd nonmated segments of the mountain pine beetle population now can be distinguished in field collections.

EYWORDS: *Dendroctonus ponderosae*, insemination, stored specimens

McCambridge (1969) observed the need for distinguishng mated from nonmated MPB (mountain pine beetles; *Dendroctonus ponderosae* Hopkins [Coleoptera: colytidae]) because of their differing reactions to pheromones. He subsequently developed an accurate method o detect sperm in live females. This enhanced evaluaon of pheromone experiments concerning MPB control nd population surveys. McCambridge's technique is nly useful for detecting sperm in live or recently killed pecimens.

But there is great need for measuring proportions of mated and unmated females that have died during other ypes of behavioral studies involving field traps—for xample, when studying the response of mountain pine eetles to lodgepole pine stands subjected to various silcultural treatments (Schmitz and others 1980). To prevent their escape, beetles caught during such studies rown in water kept in the traps (Schmitz 1984) and are subsequently transferred to vials containing 70 percent alcohol. Therefore, I initiated a study to determine if mated and unmated MPB could be distinguished among alcohol-preserved specimens.

MATERIALS AND METHODS

On October 9, 1980, several log sections were cut from a lodgepole pine naturally infested with MPB in northern Utah. The log sections were transported to Ogden, UT, and stored in a walk-in cooler at 40 °F until October 28, 1980. The logs then were moved to a laboratory and kept at room temperature (72 °F) until December, when the developing brood of the succeeding generation were force-reared to adults.

I removed egg-laying females of the 1980 generation from the logs immediately after the logs were moved to the laboratory from cold storage. The 50 females from galleries ranged in length from 15.2 to 53.3 cm (average of 30.5 cm). All egg galleries contained live eggs or young larvae, and 16 contained male adults. Because parthenogenesis does not occur in *Dendroctonus* (Gibson 1927; Reid 1962), all these females were mated. Mature unemerged females of the successive (1981) generation were removed from the same logs. In February 1982, a supplemental field collection of egg-laying females was made. I placed the females of each collection in 70 percent ethyl alcohol for later dissection and examination of the spermathecae to differentiate mated and nonmated females.

Cerezke (1964) described morphological characteristics of the MPB reproductive systems. I used his description along with a modification of McCambridge's (1969) methods of detecting live inseminated females. The spermatheca was removed by holding the female under alcohol (except for six individuals dissected under water in 1983) and grasping the base of the most distal abdominal tergite with fine forceps. The tergite was then pulled outward while holding the rest of the beetle stationary.

---

[1] Glen E. Trostle was with the Mountain Pine Beetle research work t, Forestry Sciences Laboratory, Ogden, UT, when this manuscript s prepared. He is currently at the Bee Biology and Systematics boratory, Agricultural Research Service, U.S. Department of Agriculte, Logan, UT.

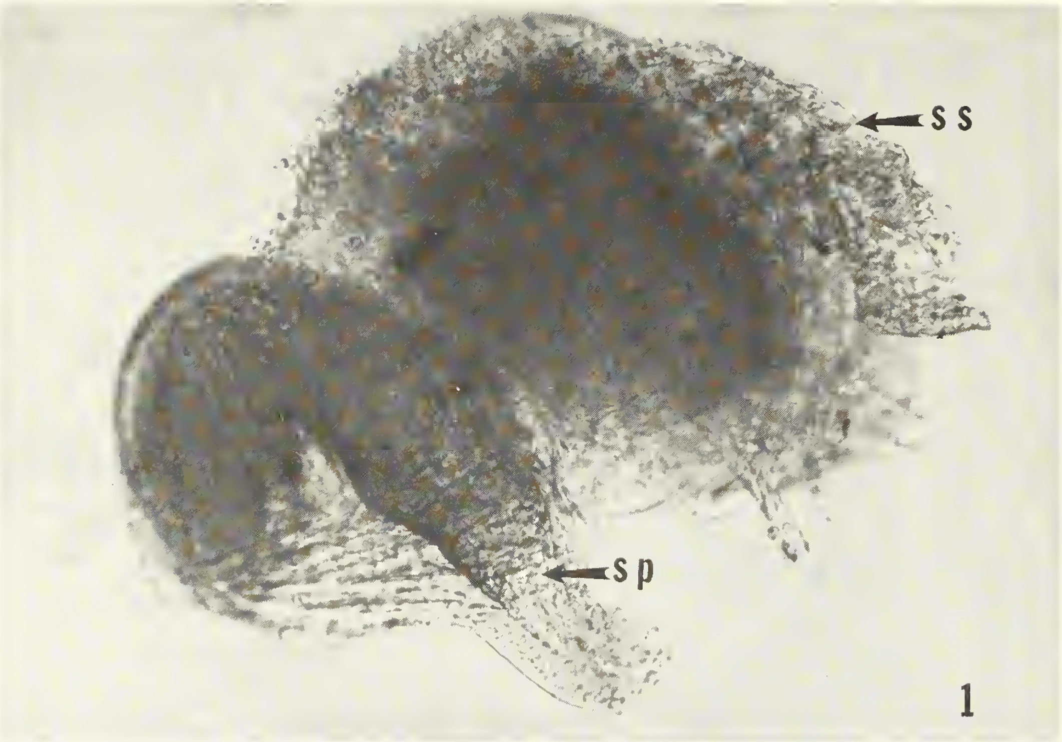


Figure 1—Spermathecal sac (ss) and pump (sp) (length = 0.84 mm) from 70 percent alcohol-preserved mated female mountain pine beetle.

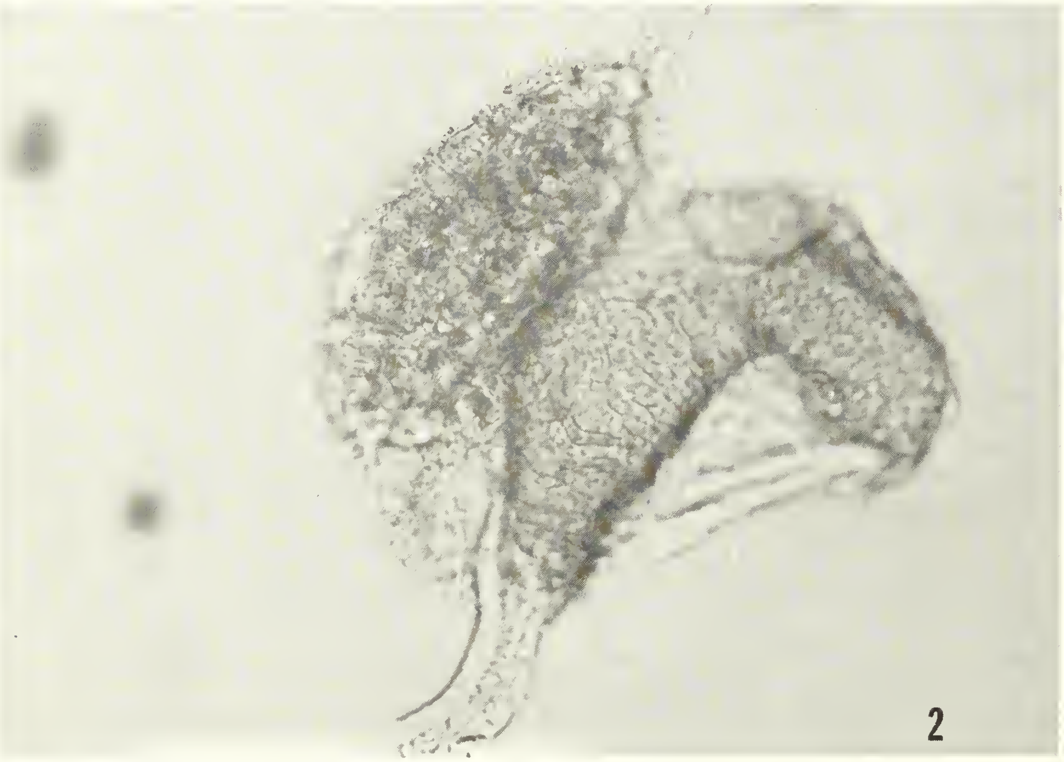


Figure 2—Spermathecal sac and pump from 70 percent alcohol-preserved unmated female mountain pine beetle.

This removed the hindgut and female genitalia. The spermatheca was then easily identified by the sclerotized bump associated with it (fig. 1).

In November 1980, I dissected 50 alcohol-preserved mated females from the first collection in the above manner and, in January and February 1981, I dissected 50 spermathecae from the females of the unmated 1981 generation. Finally, in January 1983, six additional individuals were used for photographic documentation—three unemerged females from December 1980 and three egg-laying females from the February 1982 collection.

The six females analyzed in 1983 were dissected under water and required total abdominal dissection because the internal organs had become firm by remaining in 70 percent ethyl alcohol for an extended time.

I dissected all beetles under a dissecting stereomicroscope at 16 power and 40 power under reflected light and examined the spermathecae under 40 power, using diffuse reflected light with a dark background.

RESULTS AND DISCUSSION

The spermathecae taken from mated females were opaque white, smooth, and quite rounded (fig. 1). This appearance contrasted strongly with the spermathecae removed from unmated females collected from pupal chambers in December 1980, which were translucent, grainy in appearance, and wrinkled (fig. 2).

The consistency of color and texture of the spermathecae (arising from protein fixation of the sperm by the alcohol) among all 50 mated females of variable ages suggests that an abundance of sperm is received during copulation. This probably accounts for the distinct differences in spermathecae between all mated and unmated females observed. The appearance of spermathecae from mated and unmated females remained consistent for analyses made in January 1983. Therefore, mated and unmated females can be diagnosed from alcohol-preserved specimens stored for long periods, although dissection is more difficult.

The beetles dissected in 1983 demonstrated that dissection under water was more efficient than under alcohol. This is because it was not necessary to replenish the water as it sometimes was with alcohol, and observations were unaffected by currents as occurs from evaporating alcohol. There were also no observable short-term changes of the spermathecae during dissection and analysis under water.

The results of spermathecal analysis from alcohol-preserved females demonstrate that it is an easy technique that can be used to accurately determine mated from nonmated MPB. These two segments of the mountain pine beetle population now can be distinguished in field collections.

ACKNOWLEDGMENT

I acknowledge with thanks technical reviews by Phil Torchio, Bee Biology and Systematics Lab, Agricultural Research Service, U.S. Department of Agriculture, Logan, UT, and John Schmid, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins, CO. Suggestions by Pat Bohm Trostle were indispensable in preparation of the manuscript.

REFERENCES

Cerezke, H. F. The morphology and functions of the reproductive systems of *Dendroctonus monticolae* Hopk. (Coleoptera: Scolytidae). Canadian Entomologist. 96: 477-500; 1964.

Gibson, A. K. Parthenogenesis of *Dendroctonus monticolae* Hopk. Couer d'Alene, ID: U.S. Department of Agriculture, Bureau of Entomology and Plant Quarantine; 1927. 2 p. Unpublished report.

McCambridge, W. F. Incidence of sperm in emerging female mountain pine beetles, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae). Research Note RM-137. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1969. 3 p.

Reid, R. W. Biology of the mountain pine beetle, *Dendroctonus monticolae* Hopkins, in the east Kootenay region of British Columbia. II. Behaviour in the host, fecundity, and internal changes in the female. Canadian Entomologist. 94: 605-613; 1962.

Schmitz, R. F. A passive aerial barrier trap suitable for sampling flying bark beetles. Research Note INT-348. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 8 p.

Schmitz, R. F.; McGregor, M. D.; Amman, G. D. Mountain pine beetle response to lodgepole pine stands of different characteristics. In: Berryman, A. A.; Safranyik, L., eds. Dispersal of forest insects: evaluation, theory and management implications: Symposium proceedings 2nd IUFRO conference. Pullman, WA: Washington State University, Cooperative Extension Service; 1980: 234-243.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

July 1986
Intermountain Research Station
324 25th Street
Ogden, UT 84401

nited States
epartment of
griculture

orest Service

**ntermountain
esearch Station**

esearch Note
NT-357
ugust 1986

Characterizing Succession Within a Forest Habitat Type—An Approach Designed for Resource Managers

**Stephen F. Arno
Dennis G. Simmerman
Robert E. Keane**[1]

BSTRACT

Describes a method for developing a general-purpose cological model of community types and successional lationships within a forest habitat type (potential vegeution). This model is based upon data collected from a rge number of seral stands, and it is intended for use land management and planning. The successional odel has a framework of structural stages subdivided nto community types based on overstory and underrowth composition. The usual pathways or directions of uccession between community types are identified. To id prediction of vegetational development after different eatments, the model shows apparent relationships mong posttreatment vegetation and the original vegetaon, site characteristics, and kind of treatment. This ethod was used in developing successional classificaons (models) of four major forest habitat types in westrn Montana (Arno and others 1985).

EYWORDS: vegetation classification, ecological modeling, vegetal response, effects of disturbance

Pfister (1980) concluded that no single modeling approach will meet all management and research needs for understanding succession. In fact, a diverse array of methods have been used to model various aspects of forest succession (Kessell 1981; West and others 1981; Means 1982). In the Northern Rocky Mountains several types of successional models have been developed to meet different needs (Stage 1973; Kessell and Potter 1980; Wykoff and others 1982; Fischer and Clayton 1983; Steele 1984; Steinhorst and others 1985). Nevertheless, little attention has focused on presenting successional community types in a manner that would allow resource managers to predict response to alternative treatments. The method outlined in this paper addresses this latter need by modeling succession within a "habitat type" or "vegetation association," representing the end-point of succession (Daubenmire 1968; Pfister 1984).

Our approach produces a general-purpose ecological classification of the seral community types on a given habitat type and also serves as a guide to help users confirm the habitat type of seral stands. A model shows the usual pathways of succession and allows land managers to compare results of different treatments and site conditions. An interactive computer program developed as a companion to this model supplies quantitative predictions of vegetal response to treatments (Keane 1984).

SCOPE OF THE CLASSIFICATION

To apply this classification technique, we recommend selecting a geographic area or region having similar patterns of vegetational types and zonation (Arno 1979).

---

[1] The authors are, respectively, Research Forester, Forester, and esearch Cooperator, Intermountain Research Station, located at the termountain Fire Sciences Laboratory, Missoula, MT.

For example, the western Montana classifications (Arno and others 1985) apply on about 5 million acres of land and fit less well outside of this core area. Classifying successional communities on a group of related habitat types that lie adjacent to each other allows for more efficient sampling and better insight for modeling vegetal relationships.

Successional communities arising after common disturbances or treatments are candidates for classification. For instance, our Montana classification dealt with stand-replacing wildfire, clearcutting followed by broadcast burning, clearcutting with dozer piling and burning, and clearcutting with no followup treatment. If consistent applications of any partial cutting treatment have been made over considerable acreages within a habitat type, the resulting communities can be sampled and classified. Postfire communities ranging in age from 1 year to more than 200 years may be available for sampling, whereas stands arising after clearcutting treatments commonly range up to about 30 years of age.

We recommend sampling a large representation of the posttreatment communities available and watching for the opportunity to sample adjacent untreated stands or stands with different treatments on similar topography and soils. This will yield large numbers of samples for the money invested. The determination of when to stop sampling additional stands depends on the level of resolution needed within the classification, which is a function of intensity of land management. Normally, continued sampling can be questioned when new stand data begin to show a very high proportion of redundancy.

SAMPLING PROCEDURE

The first step in selecting sample stands is to obtain information from local foresters for locating stands that represent a range of ages for each kind of treatment in each habitat type. A computer-sort of available stand inventory data can identify kinds and ages of treatment units by habitat type or by aspect-elevation criteria. Bear in mind, however, that inventory data may have errors in habitat type determination. Soil surveys can be consulted to see if the same habitat type occurs on dissimilar soils. If so, soils may be included in the stratified sampling scheme. Take reconnaissance trips to identify potential sample stands, recording the extent and homogeneity of the plant community, principal tree and undergrowth species, uniformity of treatment and site conditions, stand age, habitat type, and evidence of artificial regeneration.

After reconnaissance has been conducted in many areas, select stands for sampling with a goal of obtaining geographic dispersion of samples as well as a range of ages for all treatments and a representation of all apparently different plant communities (Pfister and Arno 1980). Stands on the same site representing different ages or treatments should be given priority for sampling because they provide comparisons of differential response to treatments and they allow indexing the treated stands to an association. After tentative selections have been made, a two-person team can sample three to six stands in a 10-hour field day.

We suggest sampling a single 375-m^2 (nearly 1/10-acre circular macroplot in each stand (Pfister and others 1977; Steele and others 1983). After inspecting the stand, the macroplot should be located subjectively in an area that seems to have a representative overstory and undergrowth composition and treatment uniformity. This for of macroplot location is termed "subjective but without preconceived bias" (Mueller-Dombois and Ellenberg 1974; Pfister and Arno 1980). The principal advantage o the single macroplot is that it enables the investigator to obtain quantitative data of adequate precision on tw fold to fourfold as many stands per day as can be sampled in methods that require many microplots. Methods that use microplots or belt transects may be required if quantification of intricate disturbance patterns is necessary, such as in studies of pocket gopher damage. Canopy coverage for each tree and undergrowth species can be estimated in broad percentage classes for the macroplot—for example, a 0 to 1 percent class; 1 to 5 percent; 5 to 15 percent; and in 10 or 20 percent classes thereafter. To enhance consistency of macroplot coverage estimates, samplers should initially compare them with averages derived from 50 small plots systematicall placed within the macroplot. The size of small plots should be related to the vegetational life-form being sa pled. The macroplot estimates can then be adjusted to coincide with values derived from small plot estimates.

In stands having a treatment mosaic, such as those resulting from bulldozer pile-and-burn operations, it ma be desirable to locate smaller sample plots in each element of the mosaic and also to estimate the percentage of the area represented by each element. It may also be possible to meet study goals in areas having a treatme mosaic by sampling one macroplot per stand, with the plot situated in an average representation of the mosai elements.

Trees in the macroplot are tallied by species and diameter size classes (for example, 2-inch classes). Stan history is determined from tree growth rings in order t augment and verify available management records. Tre regenerating after the treatment are increment-bored o cross-sectioned near ground line to obtain total age. Also, residual overstory or small understory trees that survived the treatment, including those on the unit boundary, often show growth release and mechanical scars that can be used to date the treatment (Arno an Sneck 1977).

Relative severity of treatment can be estimated in broad classes (for example, light, moderate, heavy, and extreme) from the percentage of exposed mineral soil and from average depth of humus and duff compared with untreated stands. It may be necessary to use tra sects for comparing fuel or duff reduction (Brown and others 1982). In broadcast-burned stands, changes in s color and the completeness of combustion in various si classes of down fuel provide similar insight (Ryan and Noste 1985). Treatment severity is more difficult to ra in older seral stands because of vegetal recovery; but evidence of woody fuel consumption, soil organic layer and tree survival may still make a general evaluation possible. As a minimum, texture of the mineral soil an the type of soil parent material should be recorded in ach stand. Characterization of soils to the family level desirable for evaluating potential vegetation on eated sites lacking adjacent untreated communities.

Quantitative evaluation of both natural and planted ee regeneration should be made on treated sites, and anagement records of tree planting or seeding should e checked. One simple approach is to estimate estabshed regeneration in three classes for each young and: "adequate regeneration" (for example, more than 50 well-distributed trees per acre), "inadequate regenertion" (for example, 100 to 250 trees per acre or poor istribution), and "nonstocked" (for example, less than 00 trees per acre). In order to calculate growth rates for ach species related to seral community types, heights nd total ages (from increment borings near ground vel) can be obtained from vigorous dominant or freerowing trees of each species (Pfister and others 1977).

DATA ANALYSIS

By the end of one or two field seasons, enough stands hould have been sampled to warrant the initial attempt irst approximation) at successional classification (fig. 1). lot data should be coded for computer analysis, in a rmat compatible with existing software packages.

A first step in constructing the classification is to valuate the variation within each habitat type (or ssociation), using data from all mature stands. This will etermine if the defined habitat types and phases are ufficiently detailed to serve as the basis for classifying uccessional patterns in a limited geographic area. Synhesis or association tables, index-of-similarity ordinaions (Bray-Curtis polar ordinations), cluster analyses, nd other comparable techniques are used to compare all he untreated stands in each habitat type (Mueller-Dombois and Ellenberg 1974; Gauch 1977; Volland and Connelly 1978; Pfister and Arno 1980). Data from mature stands are arranged along inferred environmental gradients (in ordinations), and consistent differences in he presence and canopy coverage of individual species nd groups of species (including herbs, shrubs, and trees) re examined (Peet 1980; del Moral 1983). The vegetaional patterns are inspected to see if they are linked to differences in site data, such as elevation, aspect, topographic position, and soils. Data from younger communiies are also inspected in a similar manner to see if comunity composition seems to reflect consistent ite-related differences within a defined habitat type or ssociation.

In the Montana successional study (Arno and others 985), we inspected data from mature stands in four reviously defined habitat types and decided to split hese into a total of seven local habitat type phases epresenting different potential vegetation types. The abitat type phases, like all other components of the uccessional classification, should be presented as a ypothesis and should be tested and critiqued by at ast three vegetation researchers. The classification will enefit if conducted as an interactive team effort, since hat will expose it to continued reevaluation and differing points of view.

Each habitat type phase identified represents the end oint of succession and thus serves as the basis for a separate successional classification or model. The model of seral community types and successional pathways within a habitat type phase is constructed using data from all stands representing the phase. In some cases it is not possible to determine the habitat type phase of a seral stand despite inspection of stumps and remnants of pretreatment communities on the site or untreated stands on similar topography and soils. It is preferable to use data from stands where the potential vegetation type can be reliably projected for construction of a successional classification. Data from stands where the potential vegetation is not predictable can later be compared to see if they fit within the successional classification.

The first step in setting up the classification framework is to define structural stages by examining the following data (or other comparable kinds of information) for each stand: years since treatment, total canopy coverage of trees, average diameter of dominant trees, and basal area of trees. Based on these data, sort the individual stands into logical structural groups. For example, the structural stages we designated in western Montana were: shrub-herb, sapling, pole, mature forest, and old-growth forest (compare with Thomas 1979; Foote 1983). In other successional studies an herbaceous stage, a seedling-dominated stage, or even a climax forest stage might be prominent and thus worthy of recognition. Criteria for each of these "structural stages" may differ among the habitat type phases because of differences in the rates of vegetal development and site productivity.

Species composition provides the criterion used in designating community types. Starting with early seral stages, identify compositionally similar groupings among the sample stands, using synthesis tables, polar ordination, cluster analyses, and so forth. Here one must employ a certain amount of judgment based upon field experience with the stands. Community types are based upon and named for major species in the overstory and undergrowth, or for individual species or groups of ecologically similar species that show consistent successional relationships.

In the successional classification (fig. 2), structural stages are arranged horizontally and community types are listed vertically. Shade-tolerant undergrowth species (for example, VAGL, *Vaccinium globulare* in fig. 2), are characteristic of pole stage and older communities; however, under certain conditions they are also major components of the younger stages. Other species are "seral dominants" (for example, CEVE, *Ceanothus velutinus*) and become common only after major disturbances. After designating the preliminary community types, construct a simple step-wise key to them for field use (fig. 3). All sample stands used in the classification should be run through the key as an initial test.

Next, the usual pathways of succession (arrows on fig. 2) should be illustrated. Probable pathways can be determined through analysis of data from sample stands of different ages, particularly those occupying the same site. Canopy coverage trends of successional species also provide evidence for pathways. For instance, coverages of evergreen ceanothus (CEVE) and young conifers are inversely related (fig. 2). In contrast, huckleberry

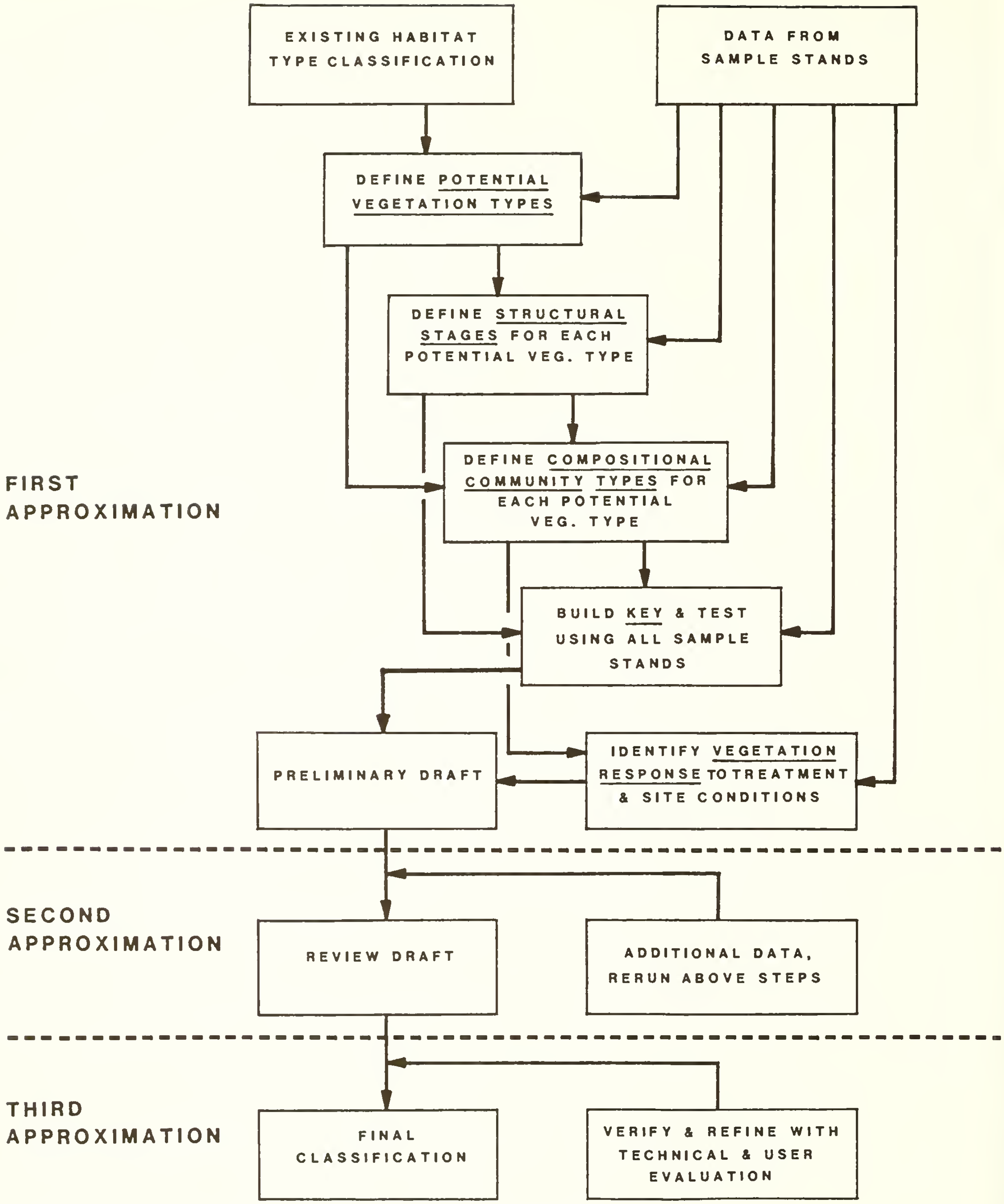
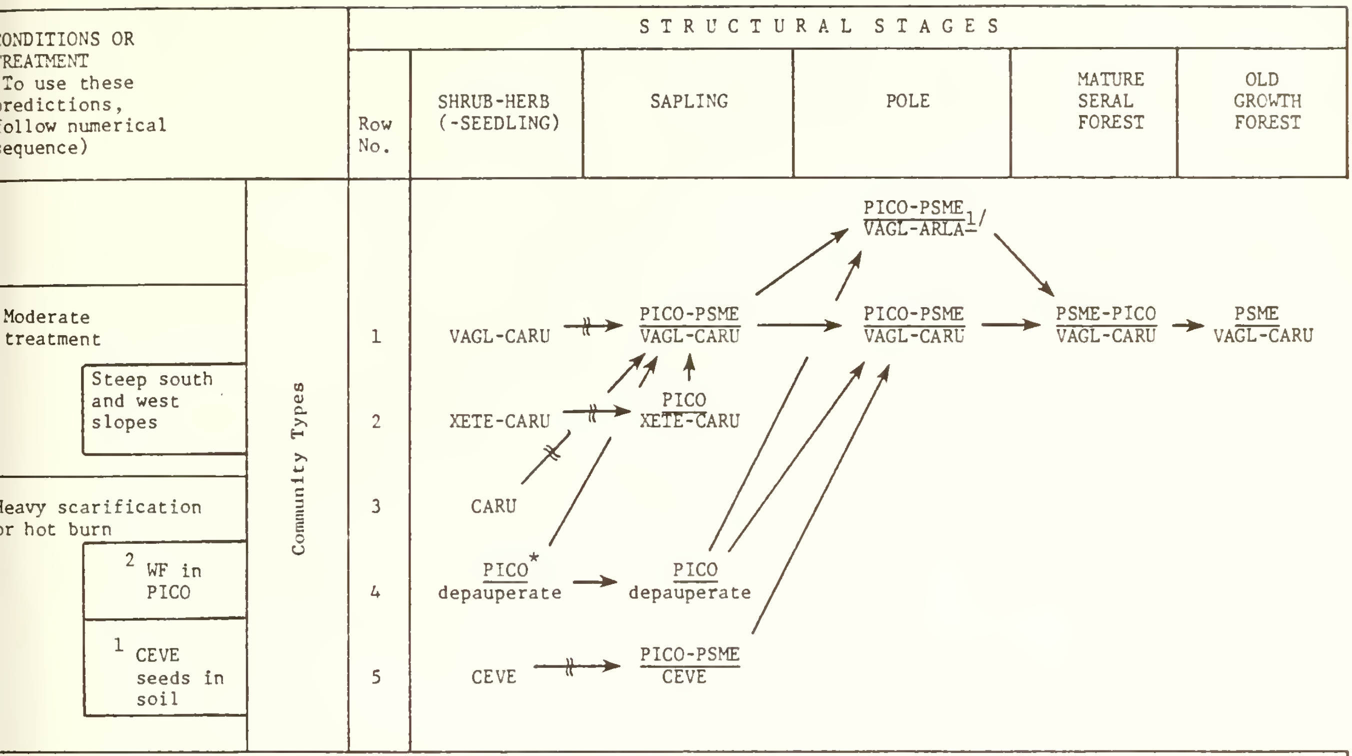


Figure 1—Flow chart showing the development of a successional classification.



/ ARLA >5% C.C.

Stand Characteristics by Structural Stage
(Range represents about 90% of the data; extreme values are shown in parentheses)

Range of values from sample stands	Tree canopy coverage percent	0 - 15(30)	15 - 90	60 - 90	55[2] - 72	45 - 70
	Average d.b.h. of dominant trees (inches)	0 - 2	2 - 5	6 - 10	11 - 16	14 - 24
	Basal area (ft^2/acre)	0 - 9	3 - 90(143)	45 - 130(321)	120 - 240	140 - 330
	Stand age (yr)	4 - 23	12 - 32(54)	(25)39 - 90	100 - 230	190 - 300+
Number of sample stands		51	33	13	9	15

REES:
PICO = *Pinus contorta*
PSME = *Pseudotsuga menziesii*
≀≀ = Establishment of tree regeneration delayed ≥ 20 years

UNDERGROWTH:
CEVE = *Ceanothus velutinus*
CARU = *Calamagrostis rubescens*
VAGL = *Vaccinium globulare*
XETE = *Xerophyllum tenax*
ARLA = *Arnica latifolia*

/ In two stands one-half or less of the coverage was from overstory trees.

igure 2—Successional community types on the PSME/VAGL habitat type, XETE hase in western Montana. The box at the left shows the apparent relationship f conditions and treatment to posttreatment community type, based on sample ata (Arno and others 1985).

VAGL) tends to expand beneath the newly developing ree layer in a sapling stand. The process of identifying robable pathways based on stand data and ecological elationships provides additional insight for evaluating nd refining the initial community type categories.

The posttreatment communities are presumably a esult of (1) the pretreatment vegetation, (2) seed disper-al from off site and from seed on the site (stored in the oil), (3) site conditions, and (4) the kind of treatment applied. The kind and intensity of treatments can be compared for each early seral community type. Similarly, pretreatment vegetation from paired stands can be compared among the early seral community types. Site characteristics (slope steepness, cool versus warm aspect, soil texture, parent material, and geographic location) can also be inspected for possible relationships to the posttreatment community types.

1. Select the most appropriate **community type row number** for the stand in question through use of the undergrowth key below (first priority). Then compare the tree species composition (second priority) with the community type names for that row in figure 2.

Stop at the first requirement that fits:	COMMUNITY TYPE ROW NUMBER (in fig. 2)
a. *Ceanothus velutinus* >5% canopy coverage (C.C.)	5
b. *Vaccinium globulare* >5% C.C.	1
c. *Xerophyllum tenax* >5% C.C.	2
d. *Calamagrostis rubescens* or *Carex geyeri* or their combined coverages >25%	3
e. Dense *Pinus contorta* seedling or saplings.	4

2. Select the most appropriate **structural stage** for the stand by comparing it with the stand characteristic values listed in figure 2 for tree canopy coverage, average d.b.h. of dominant trees, stand basal area, and stand age.

3. Inspect appendix A-3 (Arno and others 1985) which shows constancy and average canopy coverages of different species in each community type. Is the stand in question compositionally similar to sample stands shown in the indicated community type? If so, it apparently "fits" that community type. If it is dissimilar in terms of major component species, compare it with the other community types listed. It may fit one of those types, or it may not fit this classification as was the case with three of the 124 stands (2.4 percent) we sampled.

Figure 3—Key to successional community types within the PSME/VAGL habitat type, XETE phase (from Arno and others 1985).

Relationships of seral community type to treatment may be very unclear at first, but may improve as additional stand data are obtained during the course of the classification effort. These linkages are first presented as very tentative hypotheses, which are then repeatedly subjected to reevaluation as new data are obtained. Apparent relationships of the posttreatment community types to the original vegetation, site conditions, and treatment are shown in the boxes at the left in figure 2.

Substantial amounts of data obtained from paired or multiple stands on the same sites provide a basis for evaluating responses of undergrowth species to each kind of treatment. To do this, construct tables comparing canopy coverages by species in paired untreated and treated stands (table 1). Establish quantitative criteria to describe apparent trends for each species by treatment. For instance, our Montana data (Arno and others 1985) were sufficient to describe the trends of principal species as "increase," "decrease," "little change," or "variable and inconsistent changes." Species response interpretations can be improved and expanded by comparing findings from other studies dealing with similar vegetation (for example, McLean 1969; Flinn and Wein 1977; Stickney 1986; Volland and Dell 1981).

General interpretations can also be made regarding the success of artificial and natural tree regeneration by habitat type (Fiedler 1982; Arno and others 1985). Tree regeneration is compared in relation to kind and intensity of treatment and to site characteristics and competing vegetation. Artificial and natural regeneration should be rated separately; they are usually not difficult to differentiate by consulting planting records and observing spacing patterns and tree ages. More definitive assessments of regeneration require intensive surveys.

TESTING AND REFINING

It is useful to carry out sampling during a period of 2 or more years and to repeat the analysis with the expanded data bank in order to arrive at a revised successional classification or "second approximation" (Pfister and Arno 1980). This can be distributed to potential users as a review draft. We recommend holdin a workshop to introduce potential users to the successional classification and to have them try it out in the field with guidance. Considerable effort should be invested in making the classification straightforward an easy to apply for users with a modest ecological background.

We recommend setting up a verification study of the review draft classification to be conducted by an investigator who was not involved in its development. The verification consists of two parts: (1) a field test of the draft classification carried out by the investigator on large numbers of seral communities, and (2) a field test of some of these same communities carried out by potential users under the guidance of the investigator.

In the verification effort, the classification is applied to seral communities representing all of the sampled treatments in the habitat type under investigation. At

Table 1—Percentage cover for selected species within five paired *Pseudotsuga menziesii/Vaccinium globulare, Xerophyllum tenax* stands before and after a clearcut-hot broadcast burn treatment; time since treatment ranged from 14 to 23 years

Species	Pre-treatment	Post-treatment	Interpretation
VAGL	72	<1	Decrease
	54	<1	
	54	3	
	15	3	
	37	28	
CEVE	<1	<1	Increase
	0	4	
	0	15	
	<1	37	
	0	85	
XETE	72	<1	Decrease
	46	<1	
	72	15	
	37	22	
	46	46	
CARU	8	8	Little change
	15	15	
	37	15	
	3	22	
	37	37	

ach stand the evaluation procedure consists of the fol-
owing steps, with questions, problems, and suggestions
ecorded in relation to each step:

1. Select a test stand, identify its habitat type or
hase, and determine if the successional classification
hould apply to it.

2. Choose a representative area within the stand for
ampling.

3. Complete the field form recording coverages of indi-
ator species (for example, p. 74 in Arno and others
985).

4. Using the successional classification key (fig. 3),
dentify the community type.

5. To confirm the choice of a community type, com-
are compositional data from this stand with data for
he community type in the review draft.

The evaluations show how well the classification and
ey fit and point out numerous opportunities for improv-
ng clarity. The verification effort also provides addi-
ional data for refining the classifications, because
anopy coverage information is collected at each test
tand using the field form.

Users should be introduced to successional classifica-
ions via guidelines that help them determine which hab-
at type phase and, therefore, which classification
pplies to a given seral stand (for example, p. 9 in Arno
nd others 1985). The user then consults the key to the
eral community types, which is applied in conjunction
ith the classification diagram and with tables sum-
arizing species composition by community type. A nar-
ative explains the successional diagram or model.

REFERENCES

Arno, S. F. Forest regions of Montana. Research Paper INT-218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 39 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. Forest succession on four habitat types in western Montana. General Technical Report INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 74 p.

Arno, S. F.; Sneck [Davis], K. M. A method for determining fire history in coniferous forests of the Mountain West. General Technical Report INT-42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 28 p.

Brown, J. K.; Oberheu, R. D.; Johnston, C. M. Handbook for inventorying surface fuels and biomass in the Interior West. General Technical Report INT-129. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 48 p.

Daubenmire, R. Plant communities: a textbook of plant synecology. New York: Harper and Row; 1968. 300 p.

del Moral, R. Vegetation ordination of subalpine meadows using adaptive strategies. Canadian Journal of Botany. 61: 3117-3127; 1983.

Fiedler, C. E. Regeneration of clearcuts in four habitat types in western Montana. In: Site preparation and fuels management on steep terrain: Proceedings of a symposium; 1982 February 15-17; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1982: 139-147.

Fischer, W. C.; Clayton, B. D. Fire ecology of Montana forest habitat types. General Technical Report INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 83 p.

Flinn, M. A.; Wein, R. Depth of underground plant organs and theoretical survival after fire. Canadian Journal of Botany. 55: 2550-2554; 1977.

Foote, M. J. Classification, description, and dynamics of plant communities after fire in the taiga of interior Alaska. Research Paper PNW-307. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1983. 108 p.

Gauch, H. G. ORDIFLEX—a flexible computer program for four ordination techniques: weighted averages, polar ordination, principal components analysis, and reciprocal averaging. Release B. Ithaca, NY: Ecology and Systematics, Cornell University; 1977. 185 p.

Keane, R. E. Predicting successional plant composition on a *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type in western Montana. Missoula, MT: University of Montana; 1984. 72 p. M.S. thesis.

Kessell, S. R. The challenge of modeling post-disturbance plant succession. Environmental Management. 5: 5-13; 1981.

Kessell, S. R.; Potter, M. A quantitative succession model for nine Montana forest communities. Environmental Management. 4: 227-240; 1980.

Means, J. E., ed. Forest succession and stand development research in the Northwest: Symposium proceedings; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory; 1982. 170 p.

McLean, A. Fire resistance of forest species as influenced by root systems. Journal of Range Management. 22: 120-122; 1969.

Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974. 547 p.

Peet, R. K. Ordination as a tool for analyzing complex data sets. Vegetatio. 42: 171-174; 1980.

Pfister, R. D. Designing succession models to meet management needs. In: Means, J. E., ed. Forest succession and stand development research in the Northwest: Symposium proceedings; 1981 March 26; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory; 1982: 44-53.

Pfister, R. D. Forest habitat type classification in the western United States. In: International Union of Forestry Research Organizations, symposium on site and productivity of fast growing plantations; 1984 April 30-May 11; Pretoria and Pietermaritzburg, South Africa. Pretoria, South Africa: South African Forest Research Institute; 1984: 149-162.

Pfister, R. D.; Arno, S. F. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26(1): 52-70; 1980.

Pfister, R. D.; Kovalchik, B.; Arno, S.; Presby, R. Fores habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Ryan, K. C.; Noste, N. V. Evaluating prescribed fires. In: Lotan, J. E.; [and others], tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. General Technical Report INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest an Range Experiment Station; 1985: 230-238.

Stage, A. R. Prognosis model for stand development. Research Paper INT-137. Ogden, UT: U.S. Departmen of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Steele, R. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39; 1984.

Steele, R.; Cooper, S. V.; Ondov, D. M.; Roberts, D. W. Pfister, R. D. Forest habitat types of eastern Idaho-western Wyoming. General Technical Report INT-144 Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 122 p.

Steinhorst, R. K.; Morgan, P.; Neuenschwander, L. A stochastic-deterministic simulation model of shrub su cession. Ecological Modeling. 29: 35-55; 1985.

Stickney, P. F. First decade plant succession following the Sundance Forest Fire, Northern Idaho. General Technical Report INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1986. 26 p.

Thomas, J. W., tech. ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U. Department of Agriculture, Forest Service; 1979. 512 p.

Volland, L. A.; Connelly, M. Computer analysis of ecological data: methods and programs. R6-ECOL-79-00 Portland, OR: U.S. Department of Agriculture, Fores Service, Pacific Northwest Region; 1978.

Volland, L. A.; Dell, J. D. Fire effects on Pacific Nort west forest and range vegetation. Portland, OR: U.S Department of Agriculture, Forest Service, Pacific Northwest Region, Range Management Division; 19 23 p.

West, D. C.; Shugart, H. H.; Botkin, D. E., eds. Fores succession: concepts and application. New York: Springer-Verlag; 1981. 517 p.

Wykoff, W. R.; Crookston, N. L.; Stage, A. R. User's guide to the stand prognosis model. General Technic Report INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest a Range Experiment Station; 1982. 112 p.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-358

September 1986

Surface Fuel Loadings and Predicted Fire Behavior for Vegetation Types in the Northern Rocky Mountains

**James K. Brown
Collin D. Bevins**

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Surface Fuel Loadings and Predicted Fire Behavior for Vegetation Types in the Northern Rocky Mountains

James K. Brown
Collin D. Bevins[1]

ABSTRACT

Means, standard deviations, and quartiles of fuel loadings were determined for litter, for downed woody material of 0 to one-fourth inch, one-fourth to 1 inch, 0 to 1 inch, and 1 to 3 inches, for herbaceous vegetation, and for shrubs by cover types and fire groups. The studies were conducted at four locations in northwestern Wyoming, western Montana, and northern Idaho. Most distributions were strongly skewed to the right. Ratios of medians-to-means for the fuel components by vegetation type and location all averaged close to 0.6 except for shrubs, which averaged 0.18. Correlation coefficients for fuel component pairs were mostly less than 0.30. Fuel loadings and predicted fire behavior varied considerably within cover types and fire groups compared to between vegetation types. Results suggest that a few models of physical fuel properties for rating fire danger and predicting fire behavior by broad vegetation types are appropriate for practical applications. Other implications to predicting fire behavior using mathematical models are discussed.

KEYWORDS: fuel appraisal, cover types, fire groups, fuel inventory

INTRODUCTION

Determination of surface fuel loadings is necessary to predict fire behavior using mathematical models of fire spread and intensity. Fire danger rating and fire behavior prediction for fire dispatching, presuppression planning, fuel management, and other applications are important activities based on Rothermel's mathematical fire spread model (1972) and modifications by Albini (1976a). Proper application of fire behavior predictions, including development of applied systems, requires knowledge of the nature of fuel loading distributions for (1) determining appropriate fuel statistics for input to the fire behavior model and (2) interpreting meaningful resolution of the fire behavior predictions. Meaningful resolution in predicted fire behavior is uncertain because it has received limited systematic evaluation. Meaningful resolution depends on the accuracy of predictions, variability of fuels and fire behavior, and the technical requirements of managers.

The study reported here deals with the nature of fuel loading distributions and mathematical predictions of fire behavior. It was undertaken to evaluate variability in surface fuel loadings and fire behavior and to determine the statistical properties of fuel loading distributions that could be used in predicting fire behavior. The study was prompted by availability of a large set of surface fuel data gathered in the Northern Rocky Mountains during the mid-1970's primarily for establishing wilderness fire management plans. During this time, live and dead surface fuels including forest floor litter (01 horizon), downed woody material, herbaceous vegetation, and shrubs were inventoried over large areas.

METHODS

The vegetation types studied were forest cover types and "fire groups." Cover types were named according to the overstory species having the greatest basal area and included:

Common name	Scientific name	Abbreviation
Ponderosa pine	*Pinus ponderosa*	PP
Lodgepole pine	*Pinus contorta*	LP
Douglas-fir	*Pseudotsuga menziesii*	DF
Engelmann spruce	*Picea engelmannii*	ES
Subalpine fir	*Abies lasiocarpa*	AF
Grand fir	*Abies grandis*	GF
Western redcedar	*Thuja occidentalis*	C

Fire groups described by Davis and others (1980) and Fischer and Clayton (1983) consist of forest habitat types (Pfister and others 1977) that are grouped based on the response of the tree species to fire and the roles these tree species take during succession. The fire groups studied included:

Fire Group Two:	Warm, dry ponderosa pine habitat types
Fire Group Four:	Warm, dry Douglas-fir habitat types
Fire Group Six:	Moist Douglas-fir habitat types
Fire Group Seven:	Cool habitat types usually dominated by lodgepole pine
Fire Group Eight:	Dry, lower subalpine habitat types
Fire Group Nine:	Moist, lower subalpine habitat types

---

[1] Project leader at the Intermountain Fire Sciences Laboratory, Missoula, MT, and research forester with Systems for Environmental Management in Missoula.

Fire Group Ten:	Cold, moist upper subalpine and timberline habitat types
Fire Group Eleven:	Moist grand fir, western redcedar, and western hemlock habitat types.

The following areas were studied:

1. Cooper Queen (CQ), Bitterroot National Forest, western Montana.
2. Tolan Creek (TOL), Bitterroot National Forest, western Montana.
3. Moose Creek and White Cap Creek (MWC), Selway-Bitterroot Wilderness, Nez Perce and Bitterroot National Forests, northern Idaho.
4. Teton Wilderness (TET), Bridger-Teton National Forest, northwestern Wyoming.

Sampling Design

Many stands, identified by overstory cover type, were selected from large areas for fuel sampling. Selected stands were identified on aerial photographs and then located in the field. Stands were also selected while hiking on and off trails. Stand selection was not entirely random; however, effort was made to systematically and objectively distribute stands throughout entire drainages.

Within each stand, three to 20 sample points were located along paced transects that cut across changes in elevation and aspect. Habitat types were identified at each sample point and provided the basis for stratifying the data into Fire Groups. All live and dead surface fuels were inventoried using a combination of techniques described by Brown and others (1982).

Analyses

All fuel loading data gathered within stands were pooled by vegetation types at each location. Only data from stands with at least eight sample points were accepted. Means, standard deviations, and quartiles were computed for the following fuel components by vegetation type and location:

— Litter (loosely cast needles, leaves, bark flakes, dead matted grass, and a variety of miscellaneous vegetative parts excluding downed woody material).

— 0- to ¼-inch diameter downed woody material in and above the litter.

— ¼- to 1-inch diameter downed woody material.

— 0- to 1-inch diameter downed woody material.

— 1- to 3-inch diameter downed woody material.

— Herbaceous vegetation (all upright live and dead grasses, sedges, forbs, and small, low-growing woody plants such as bunchberry [*Cornus canadensis*], twinflower [*Linnaea borealis*], prince's pine [*Chimaphila umbellata*], and kinnikinnick [*Arctostaphylos uva-ursi*]).

— Shrubs (leaves and live and dead stemwood less than 0.8 inch diameter).

The Kolmogorov-Smirnov two sample test (Sokal and Rohlf 1981) was used to test whether pairs of fuel distributions were identical. Loadings for each fuel component were contrasted between all possible pairs of vegetation type/location combinations. This test is sensitive to differences in the entire distributions of two samples. Correlation between fuel components was evaluated using Spearman's rank correlation coefficient (Sokal and Rohlf 1981). Nonparametric statistical tests were appropriate because the fuel loading distributions were not normally distributed.

Fire behavior was predicted using medians of each pooled fuel loading data set as input to program FIREMOD (Albini 1976b). The purpose of predicting fire behavior was to evaluate variability in fire behavior due to variability in the physical properties of fuel that characterize vegetation types. In the analyses, fuel loading was the primary source of variation. Other properties of fuel were held constant within vegetation types and locations. Fuel depth was calculated as total fuel loading divided by fuel bulk density. Total fuel loading was the sum of loadings for litter, downed woody material of 0 to 3 inches, herbs, and shrubs. Fuel bulk densities were average values reported for similar vegetation (Brown 1981).

In predicting fire behavior, fuel loadings were partitioned into litter and mixed-upright dominant fuel groups using the allocation procedure described by Brown (1981). Bulk densities were assigned to each dominant fuel group based on vegetation type. Fire behavior predicted for the litter and mixed-upright dominant fuel groups was then averaged, weighted by percent cover of each dominant fuel group. The average fire behavior values were used in further analysis and are reported in the results section.

Surface area-to-volume ratios for predicting fire behavior were as follows:

Fuel component	**Ratio**
	Ft²/ft³
Litter	1,500
0- to ¼-inch	270 to 490
¼- to 1-inch	90
1- to 3-inch	30
Herb live	1,500
Herb dead	3,500
Shrub foliage	3,000
Shrub stems 0- to 0.2-inch	610
Shrub stems 0.2- to 0.8-inch	175

For each pooled data set, fire behavior was predicted for 1- and 5- mi/h midflame windspeed at the following low and high dead fuel moisture contents (ovendry basis):

	Moisture content	
Fuel component	**Low**	**High**
	-------- *Percent* --------	
Herb	4	12
Litter	4	12
0- to ¼-inch	4	12
¼- to 1-inch	5	16
1- to 3-inch	8	16

These dead fuel moisture contents represent the 10th and 75th percentile values of cumulative moisture content distributions computed from weather records covering 1954 to 1981 at two weather stations near the study areas. Live fuel moisture content was held constant at 100 percent. The fraction of herbaceous vegetation considered dead was based on the inventory data and ranged from 0.05 to 0.15 among the vegetation types.

Most stands were sampled with too few plots for reliable prediction of fire behavior on a stand basis. Thus, a jackknife method (Sokal and Rohlf 1981) of assessing variability in fire behavior was attempted. Groups of data were generated from the pooled data set by eliminating 10 randomly drawn sample points. The process was repeated until all plots were eliminated in sets of 10. Previously drawn samples were replaced after each draw but could not be redrawn. Fire behavior was predicted for each jackknife group using median fuel loadings.

FUEL CHARACTERISTICS

Mean and quartile fuel loadings for cover types are shown in table 1. Most of the values in table 1 were significantly different at the 95 percent confidence level

able 1—Mean and quartile loadings by cover type and location for fuel categories used in predicting fire behavior (see text for information on cover type and location abbreviations)

			Litter				0- to ¼-inch			
Cover ype	Location	Number samples	Mean	First quartile	Median	Third quartile	Mean	First quartile	Median	Third quartile
			Lb/acre							
LP	CQ	242	760	160	365	875	320	120	235	390
	MWC	376	1,180	335	655	1,325	430	160	290	565
	TET	296	1,980	530	1,385	2,550	410	115	275	550
	TOL	411	585	185	310	580	255	80	195	350
DF	CQ	297	745	90	225	665	255	60	165	310
	MWC	553	1,080	245	635	1,265	570	165	380	785
	TOL	200	295	90	205	365	490	85	320	670
AF	MWC	182	725	150	390	800	135	40	85	175
	TOL	86	510	145	295	620	225	55	115	220
ES	MWC	113	1,035	320	615	1,230	355	85	195	420
	TET	191	1,920	365	1,020	2,250	240	80	175	345
GF	MWC	483	1,330	275	625	1,290	445	150	320	595
C	MWC	205	1,705	575	985	1,625	595	290	510	780
PP	MWC	494	1,250	0	675	1,780	235	0	110	270
			¼- to 1-inch				1- to 3-inch			
LP	CQ	242	1,175	0	660	1,875	6,255	0	3,200	9,710
	MWC	376	1,360	0	645	1,930	1,215	0	0	0
	TET	296	1,370	0	625	1,875	2,830	0	0	2,985
	TOL	411	1,445	625	1,250	1,890	5,180	0	3,060	8,950
DF	CQ	297	1,245	0	665	1,910	3,285	0	0	3,730
	MWC	553	1,905	635	1,305	2,540	1,685	0	0	3,210
	TOL	200	1,850	0	1,330	2,745	4,705	0	3,245	6,745
AF	MWC	182	865	0	490	985	965	0	0	0
	TOL	86	1,380	480	955	1,910	5,645	0	3,335	9,710
ES	MWC	113	1,740	440	880	2,205	1,570	0	0	2,730
	TET	191	1,250	0	855	1,710	3,860	0	2,720	5,440
GF	MWC	483	1,025	380	765	1,150	15	0	0	0
C	MWC	205	1,540	570	1,145	2,280	1,470	0	0	2,555
PP	MWC	494	835	0	370	1,085	1,475	0	0	0
			Herb				Shrub			
LP	CQ	242	1,295	705	1,175	1,670	415	0	10	20
	MWC	376	1,285	245	685	1,825	660	20	225	810
	TET	296	700	210	465	980	70	0	0	0
	TOL	411	1,615	335	1,135	2,240	250	0	90	355
DF	CQ	297	750	350	570	885	105	5	20	85
	MWC	553	470	80	215	435	1,015	15	80	320
	TOL	200	985	285	465	1,135	155	0	15	115
AF	MWC	182	2,810	590	2,105	3,840	290	0	5	130
	TOL	86	1,200	100	395	1,565	390	0	260	465
ES	MWC	113	1,065	190	455	1,400	570	5	165	780
	TET	191	790	420	690	995	105	0	0	65
GF	MWC	483	475	105	230	480	360	10	35	185
C	MWC	205	240	80	185	260	290	0	10	50
PP	MWC	494	270	0	150	405	295	0	5	135

from all other values. Only 13 percent of the 252 Kolmogorov-Smirnov tests between cover type/location combinations were nonsignificant. The 0- to 1-inch category had considerably more nonsignificant differences than either the 0- to ¼-inch or the ¼- to 1-inch categories. This suggests that the broader the diameter limits are for downed woody material, the more difficult it is to detect significant differences in fuel loadings.

Most of the loading distributions were highly skewed, having long right-handed tails. Some distributions such as the 1- to 3-inch woody material and shrubs contained many zero observations. Shrub loadings were especially highly skewed as shown by the ratios of medians-to-means and ratios of standard deviations-to-means (table 2). The ratios of medians-to-means for litter, downed woody fuels, and herbaceous vegetation all averaged close to 0.6. The strong right-handed skewness in naturally occurring fuel distributions has also been reported by Brown and See (1981) and Jeske and Bevins (1979). Most fuel distributions are skewed because dead material, especially limbwood, often accumulates in clusters or jackpots. Shrubs and herbaceous vegetation often grow in clumps. Sparse fuel quantities commonly exist between fuel concentrations.

Some discussion of individual fuel components may be of interest.

Litter—Mean loadings ranged from 295 to 1,980 lb/acre. The wide range may be due in part to inconsistencies in sampling. The subjective definition of litter coupled with different individuals doing the sampling probably introduced variability. For comparison, Jeske and Bevins (1979) reported litter loadings of 1,980 lb/acre in Glacier National Park forests. In Arizona, ponderosa pine needle litter averaged 2,000 lb/acre and mixed-conifer litter averaged 2,200 lb/acre (Sackett 1979). Litter can markedly affect predicted fire behavior because loadings of this finely divided fuel are often high compared to other fuel components. Litter for fire behavior prediction should include the loosely cast plant material that will burn during passage of a flame front. In sampling, the difficulty in recognizing what is litter and what is not litter can easily lead to imprecise predictions of fire behavior.

0- to ¼-inch—Mean loadings ranged from 135 to 595 lb/acre. The smallest loadings occurred in the ponderosa pine and subalpine fir cover types perhaps because ponderosa pine grows little 0- to ¼-inch twig material (Brown 1978). Subalpine fir trees tend to retain their branches rather than shed them due to lack of natural pruning and a characteristic narrow crown shape that resists breakage. For comparison, loadings in Glacier National Park forests ranged from 375 to 945 lb/acre measured over different years since last burn (Jeske and Bevins 1979).

¼- to 1-inch—Mean loadings ranged from 835 to 1,905 lb/acre, a reasonably small range. In Glacier National Park, loadings averaged 1,195 lb/acre and varied significantly over the period that fire-killed trees were deteriorating (Jeske and Bevins 1979). Loadings from many managed stands for the same cover types in western Montana and northern Idaho averaged 1,800 to 2,600 lb/acre (Brown and See 1981). The higher loadings are probably due to cutting activity in some stands.

1- to 3-inch—Loadings varied considerably between individual sample points, with mean loadings ranging from 15 to 6,255 lb/acre. All of the first quartiles and over half of the medians were zero. Most nonsignificant differences using the Kolmogorov-Smirnov test were for this fuel component. Apparently, a sampling plane length longer than the 6.8 feet used in the data collection was needed to provide more realistic and meaningful loading distributions. A 10- or 12-foot long sampling plane would probably have produced considerably fewer zero observations and better data.

0- to 1-inch—Mean loadings ranged from 1,000 to 2,340 lb/acre. Combining the 0- to ¼-inch and ¼- to 1-inch size classes reduced variability from that found in the 0- to ¼-inch class but not from that found in the ¼- to 1-inch class.

Herb—Mean loadings ranged from 240 to 2,810 lb/acre. The high loadings probably represent beargrass (*Xerophyllum tenax*) and elk sedge/pinegrass (*Carex geyerii/ Calamagrostis rubescens*) communities. Herbaceous vegetation can vary considerably from year to year, thus the large range is not surprising. Interestingly, the mean loading for lodgepole pine at Cooper Queen and the Moose Creek and White Cap Creek locations were essentially the same at 1,290 lb/acre. The median loading, however, at Cooper Queen was 1,175 lb/acre, almost twice that of 685 lb/acre at the other location. In this situation, if fire behavior predictions were based on mean loadings, no differences would be predicted between locations. However, if based on median loadings, considerably different fire behavior predictions would result. The converse situation with similar medians and dissimilar means is probably more apt to occur, as indicated in table 1.

Shrub—Mean loadings ranged from 70 to 1,285 lb/acre. Medians were much smaller than means because of the aggregated pattern of shrub growth. Use of medians in

Table 2—Ratios of medians-to-means and ratios of standard deviations-to-means for the 14 cover type-location data sets

Statistic	Litter	0- to ¼-inch	¼- to 1-inch	0- to 1-inch	1- to 3-inch	Herb	Shrub
			Ratio of median-to-mean				
Low	0.30	0.46	0.44	0	0	0.33	0
High	.70	.85	.86	0.85	0.71	.91	0.67
Mean	.55	.66	.62	[1].63	[1].57	.62	[1].18
			Ratio of standard deviation-to-mean				
Mean	1.58	1.19	1.23	1.18	1.75	1.26	4.06

[1] Excludes observations with 0 median.

predicting fire behavior probably misrepresents fire behavior in patches of shrubs, but probably provides the most accurate predictions of average rate of spread and intensity in other fuels.

Variation in mean loadings within cover types is rather large and greater than variation between many cover types (fig. 1). Although this study was not designed to evaluate surface fuel variability, it does suggest that differences between many cover types may be insignificant for applications to fire management. However, variation within cover types may be important and may require assessment for rating fire danger and appraising potential fire behavior.

Correlations Between Fuel Components

Practically all correlation coefficients were significant due to the large amounts of data. However, correlations were low, indicating little association among fuel variables (fig. 2), which Brown and See (1981) also concluded. Number of observations ranged from 670 to 2,190 among the cover types, except for redcedar with 260 observations. Most of the correlation coefficients for redcedar were nonsignificant at the 0.05 confidence level, thus the redcedar coefficients were omitted from figure 2. A larger data set was used for correlation analysis than for the loading distributions because all available data were analyzed, which included many stands with only a few sample points.

The 0- to ¼-inch and ¼- to 1-inch size classes were the most highly correlated of all the variable pairs, having a median correlation coefficient for the cover types of 0.41. This moderate correlation seems reasonable because branches shed from trees should contain materials from both size classes. However, the low correlations between most downed woody classes indicate that downfall and deterioration of twigs, branches, and boles is not uniform among the different size classes.

Litter and grass loadings were inversely related except in the ponderosa pine type where litter (comprised primarily of dead grass) and grass were positively correlated. Correlations were not evaluated for some fuel components because they were sampled at different subplot locations and because variation in loading over short distances was high for one or both components. In general, the low correlations suggest that in modeling fuels for prediction of fire behavior, fuel components are highly independent.

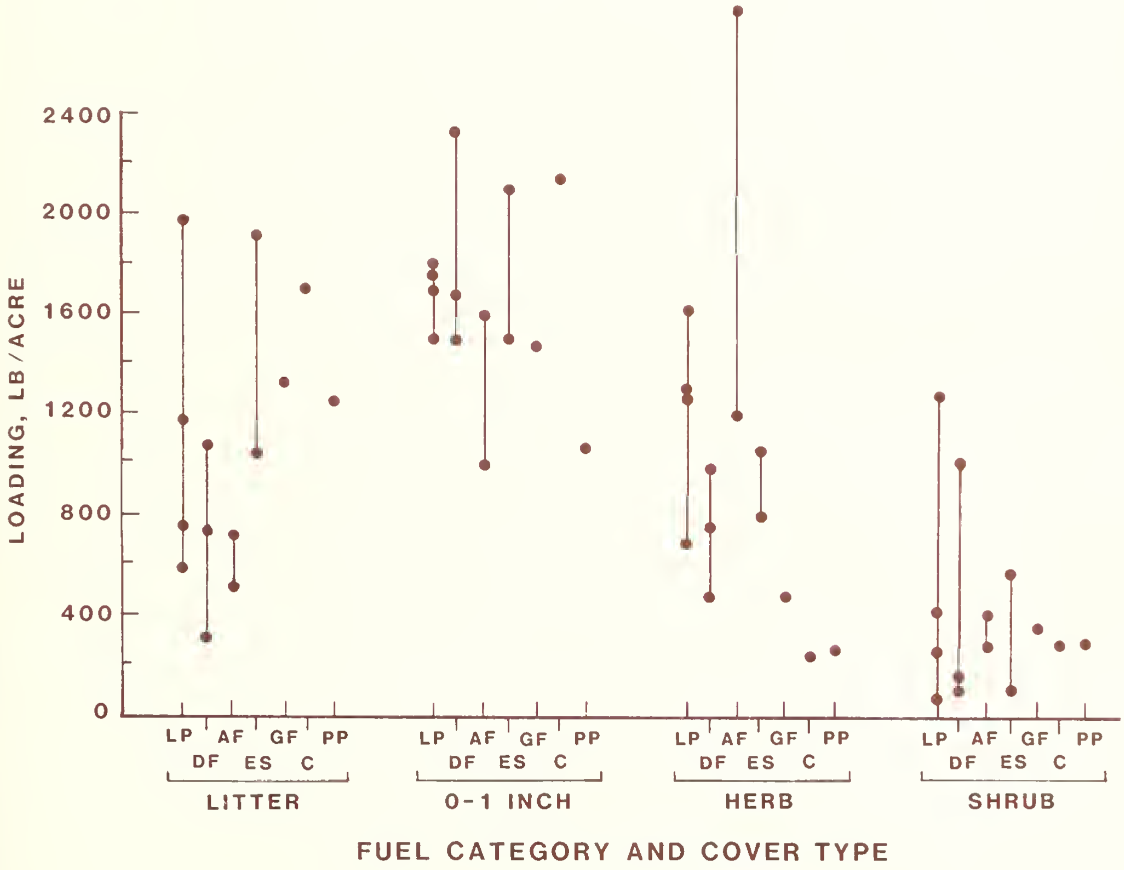


Figure 1—Plotted points represent mean fuel loadings of selected fuel categories for cover types and locations. Variation within cover types is shown by lines connecting different locations. Cover types are represented by one to four locations. (See text for information on abbreviations.)

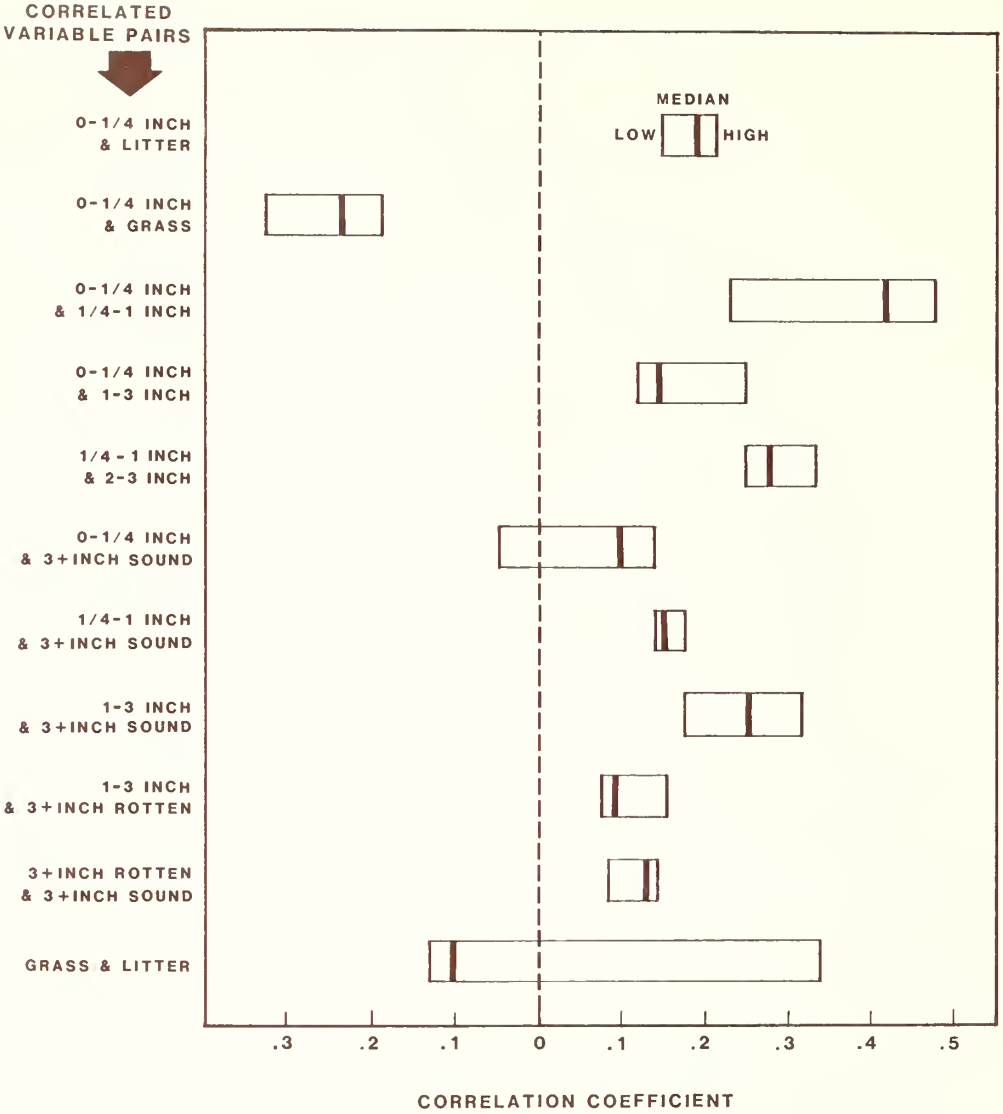


Figure 2—Spearman's correlation coefficients between pairs of fuel variables. The range and median of correlation coefficients from cover types are shown. Coefficients exceeding ±0.10 are significant at the 0.05 confidence level.

Fuel loading distributions for the fire groups were similar to those for the cover types. Approximately 70 percent of the fuel loading distributions for fire group-location data sets were significantly different according to the Kolmogorov-Smirnov test. A smaller proportion of the fuel distributions were significantly different for the fire groups than for the cover types, indicating more similarity of fuels between fire groups. The ratios of medians-to-means and standard deviations-to-means were essentially the same for cover types and fire groups. Variation in loadings within and between fire groups appeared similar to that of cover types (fig. 3); and like cover types for fire management applications, it suggests that differences between fire groups may be insignificant but variation within fire groups may be important.

FIRE BEHAVIOR

Average rates of spread and fireline intensities for low fuel moisture and 5-mi/h midflame windspeed are shown for cover types in figure 4 and for fire groups in figure 5. Relative differences in fire behavior between cover types and between fire groups for the other fuel moisture-windspeed combinations were about the same. Fire behavior for some cover types may appear unrealistic. For example, rate of spread for ponderosa pine appears low compared to Engelmann spruce (fig. 5). This is probably an anomaly. In reality, fuel moisture contents and midflame windspeeds common to these cover types would favor higher rates of spread and fireline intensities for ponderosa pine than for Engelmann spruce. Thus, figures 4 and 5 do not necessarily reflect actual field situations.

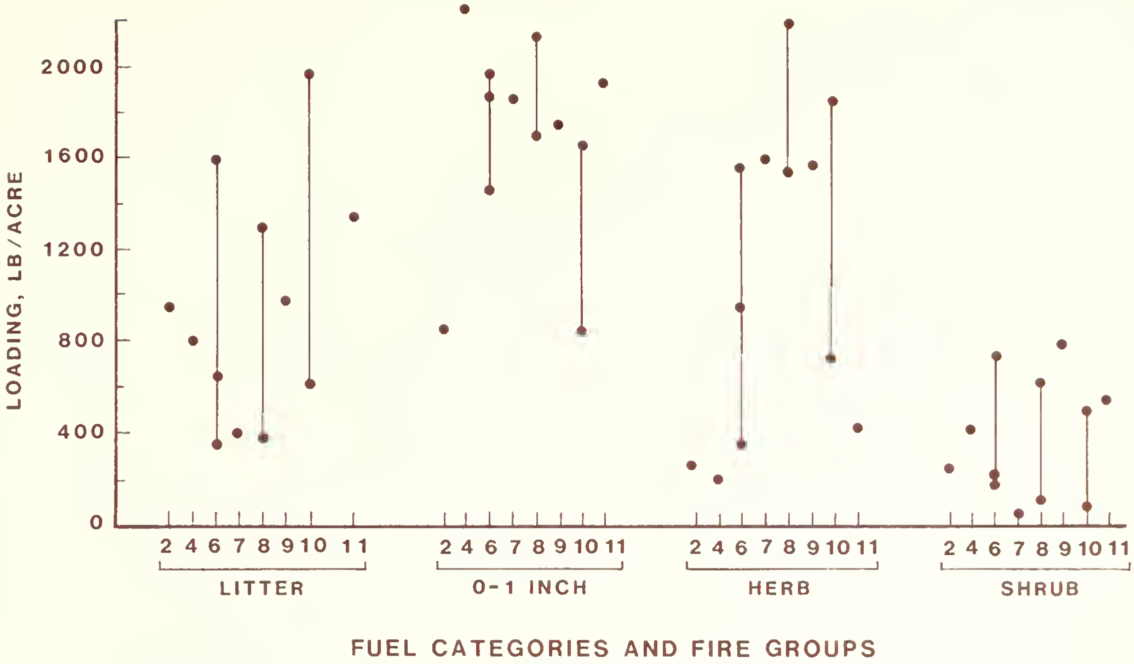


Figure 3—Plotted points represent mean fuel loadings of selected fuel categories for fire ecology groups and locations. Variation within fire groups is shown by lines connecting different locations. Fire groups are represented by one to three locations. (See text for descriptions of fire groups.)

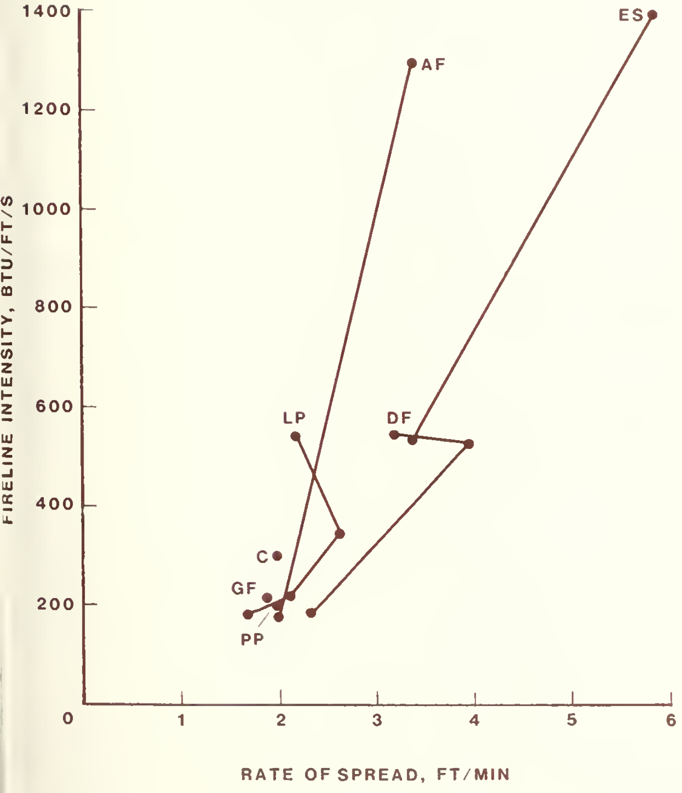


Figure 4—Plotted points represent average fireline intensities and rates of spread from the jackknife analysis of cover type/location data sets. Lines connect different locations having the same cover type. Predicted fire behavior was based on the low fuel moisture contents and 5-mi/h midflame windspeeds.

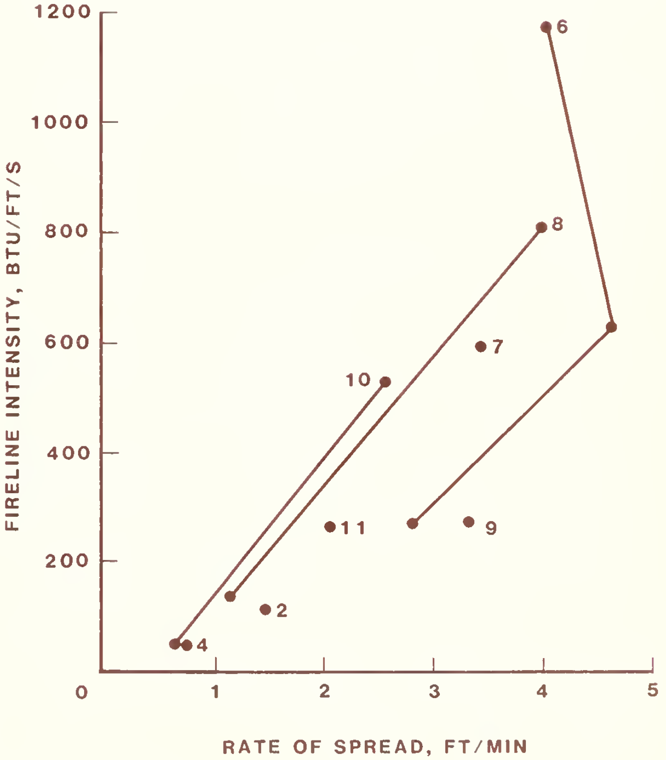


Figure 5—Plotted points represent average fireline intensities and rates of spread, from the jackknife analysis of fire groups/location data sets. Lines connect different locations having the same fire group. Numbers refer to fire groups. Predicted fire behavior was based on the low fuel moisture contents and 5-mi/h midflame windspeeds.

However, the purpose of the analysis was to evaluate the influence of only the physical fuel properties on predicted fire behavior.

Although the results are only suggestive, they reflect high variation in both rate of spread and fireline intensity within cover types (fig. 4) and within fire groups (fig. 5) as shown by the lines connecting data points. Differences in fire behavior between cover types and between fire groups appear meaningful for only a few vegetation pairs such as between Fire Groups Six and Ten. Lodgepole pine and Douglas-fir cover types differ noticeably in rate of spread but not in intensity. Some vegetation types were only represented by one location, so assessment of variation within those vegetation types was not possible.

In appraising fire behavior for broad scale application it appears that the physical properties of fuel, particularly loading, are not as important as fuel moisture and condition of live vegetation, which relate largely to season, elevation, and aspect. A few models of varying physical properties should be ample for rating fire danger or appraising fire behavior potential by broad vegetation types.

The jackknife analysis resulted in significant differences in average fire behavior between practically all cover type/location pairs and between fire group/location pairs. Variation in predicted fire behavior between the jackknife groups was exceedingly small because the median loadings of each fuel component were nearly the same.

The jackknife procedure involving analysis of medians of rather large data sets was not helpful in evaluating variation in fire behavior. Use of means would have increased variation in the predicted fire behavior. However, the overriding handicap for evaluating variation in fire behavior within and between vegetation types was the fact that the data were not collected for this purpose. To definitely evaluate variability in fire behavior for vegetation types, other sampling designs and analysis techniques would be needed.

SUMMARY AND CONCLUSIONS

This study showed that distributions of fuel loading were strongly skewed to the right. Median loadings for most fuel components were approximately 0.6 of mean loadings. The choice of mean or median loadings can greatly affect predicted fire behavior. Either statistic may be appropriate depending upon the one that furnishes the most accurate fire behavior predictions and the intended applications. Median loadings better reflect the arrangement of fuels that would be encountered by a fire front spreading across an area. Thus, predictions based on medians should be more representative of fire behavior. Mean loadings should provide predictions that better reflect potential fire behavior in areas of concentrated fuel. When comparing vegetation types, mean loadings are more apt to indicate differences in fire behavior than are median loadings, when none probably exist, due to occurrence of fuel jackpots and sampling errors.

Correlation coefficients for relationships between fuel components were low, mostly less than 0.30. The weak dependence between fuel components indicates that relating fuel quantity of one component to that of another, which could simplify fuel modeling, is not realistic.

Variation in fuel loadings and predicted fire behavior within cover types and fire groups was rather large compared to variation between many vegetation types. This suggested that only a few models of physical fuel properties are sufficient to reflect fire behavior differences between vegetation types for fire management planning activities. When knowledge of expected fire behavior is needed for specific locations, site-specific appraisal of fuels is necessary to predict fire behavior.

REFERENCES

Albini, Frank A. Estimating wildfire behavior and effects. General Technical Report INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976a. 92 p.

Albini, Frank A. Computer-based models of wildland fire behavior: a user's manual. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976b. 68 p.

Brown, James K. Weight and density of crowns of Rocky Mountain conifers. Research Paper INT-197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1978. 56 p.

Brown, James K. Bulk densities of nonuniform surface fuels and their application to fire modeling. Forest Science. 27(4): 667-683; 1981.

Brown, James K.; See, Thomas E. Downed dead woody fuel and biomass in the Northern Rocky Mountains. General Technical Report INT-117. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 48 p.

Brown, James K.; Oberheu, Rick D.; Johnston, Cameron M. Handbook for inventorying surface fuels and biomass in the Interior West. General Technical Report INT-129. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 48 p.

Davis, Kathleen M.; Clayton, Bruce D.; Fischer, William C. Fire ecology of Lolo National Forest habitat types. General Technical Report INT-79. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 77 p.

Fischer, W. C.; Clayton, Bruce D. Fire ecology of Montana forest habitat types east of the Continental Divide. General Technical Report INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 83 p.

Jeske, Bruce W.; Bevins, Collin D. Spatial and temporal distribution of natural fuels in Glacier Park. In: First conference on scientific research in National Parks, Vol. II. Washington, DC: U.S. Department of the Interior, National Park Service; Transactions and Proceedings Series 5: 1219-1224; 1979.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Rothermel, Richard C. A mathematical model for fire spread predictions in wildland fuels. Research Paper

INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 40 p.

Sackett, Stephen S. Natural fuel loadings in ponderosa pine and mixed conifer forest of the Southwest. Research Paper RM-213. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 10 p.

Sokal, Robert R.; Rohlf, F. James. Biometry. 2d ed. San Francisco: W. H. Freeman; 1981. 859 p.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

A 13.79: INT- Research Note number 359
is missing from our collection and
cannot be obtained.

United States
Department of
Agriculture

Forest Service

ntermountain
Research Station

Research Note
NT-360

September 1986

Using Aerial Photos to Fingerprint a Stand for Root Disease Research

N. E. Martin[1]
R. E. Williams

ABSTRACT

Studying root rot in individual timber stands often requires accurate mapping and identification of diseased stumps, stump diameter, tree species, and cause of decay. Three stand-mapping methods were compared: (1) freehand sketches, (2) partial tracings from an aerial photo on an overhead projector, and (3) black and white enlargements of 1:1200 color aerial photos. Sketches and tracings were inaccurate or not true to scale. The photo prints could be accurately and efficiently interpreted in the field and data could be noted directly on the photos for later analysis.

KEYWORDS: stand mapping, aerial photo, root rot

INTRODUCTION

Land managers usually map the locations of root rot problem areas to show where management alternatives must be identified, because like insect problems, root-rotting organisms perennially expand their domain and also prevent acceptable afforestation of infested areas. Annual volume losses due to root diseases in the West are estimated to be 237.4 million cubic feet (Smith, R.S. 1984). Aerial reconnaissance of the northern Rockies has shown 0.2-5.1 percent of the commercial timberlands to be void of trees because of root rots (Byler 1982; James and others 1984; Williams and Leaphart 1978). In seven National Forests of northern Idaho and western Montana, these nontimbered pockets translate into 78,000 acres (31,600 ha) (James and others 1984), a condition that will persist for generations.

When studying root rot in individual timber stands, researchers usually attempt to map and identify root-diseased stumps, stump diameter, tree species, and cause of decay (Thies and Hoopes 1979). This research note reports three stand-mapping methods, one of which—aerial photo enlargements interpreted in the field—proved to be the most efficient and accurate.

All three methods were evaluated on the same stand, cutting unit 4 of the Lonesome Creek sale on the Fernan District, Coeur d'Alene National Forest, ID. The mixture of tree and shrub species is typical of the *Tsuga heterophylla/Pachistima myrsinites* and *Abies grandis/ Pachistima myrsinites* habitat types (Daubenmire and Daubenmire 1968). The 11-acre (4.5-ha) cut is bounded on the west by a major ridge, on the east by the bottom of the drainage, and lies on 30 to 40 percent slopes. The topography is a gently rolling series of secondary ridges across the contours of the major north-to-south ridge.

MAPPING METHODS EVALUATED

Freehand Sketches—The first method used the simplest of materials: 8½- by 11-inch (21.5- by 28-cm) rainproof paper on a clipboard, and 2HB lead pencils. Standing on stumps and down trees facilitated viewing as large an area as possible. Large features were freehand-sketched to scale in their relative locations, and then increasingly smaller features were added. Notations of stump diameter, tree species, and cause of visible decay (Partridge and Miller 1974) were made near each symbol for a stump. Usually about one-fourth acre could be viewed from one location and mapped on one sheet of paper.

When the view was limited to less than an acre, illustrations of one-fourth acre were more accurate than when the view covered 3 to 5 acres. It was more difficult to maintain scale throughout the number of pages necessary to accommodate the larger view. Scale was also influenced by whether the view was upslope or downslope. Regardless of the direction of view or size of area viewed, neither individual stumps nor distances among them could be effectively recorded or subsequently identified with confidence over the 11-acre (4.5-ha) area.

Freehand Sketcnes/Aerial Photo Projections—The second method relied on an overhead projector and color aerial photos of the study area. Projections of approximately one-fourth acre were made onto the paper and prominent features were traced, especially patterns of

---

[1] Plant pathologist located at Intermountain Station's Forestry Sciences Laboratory, Moscow, ID, and plant pathologist, Forest Pest Management, Intermountain Region, U.S. Department of Agriculture, Forest Service, Boise, ID, respectively.

down trees and large stumps. Pitch accumulated on the periphery of western white pine stumps photographed as white rings. These stumps were noted on the tracings and were used in the field as reference points for matching a tracing and a specific stump. Notations of stump diameter, tree species, and cause of visible decay were made for each stump 3.5 inches (9 cm) or larger in diameter.

Problems with consistency of scale among sketches needed for a composite of the 11-acre (4.5-ha) area were overcome by using the opaque overhead projector. Also, numerous stump surfaces could be traced accurately, thereby locating a number of stumps in accurate proximity to each other. Many other features could be traced onto the papers such as prominent clusters of shrubs, rock outcrops, or patterns formed by logs left on the site. These features, as well as specific large stumps or groups of small stumps, could be used to locate on the ground the area depicted in the tracing, then remaining stumps could be sketched in relation to these features. It was soon apparent that the locations sketched among the traced locations had the errors inherent in freehand sketching as previously mentioned. These errors negated any advantage of partially traced locations. Tracing of a projected image with sketching was as unacceptable as sketching alone!

Accuracy of tracings could be improved by recording additional details from the photos and by locating stumps with greater precision. Eleven person-days were used in preparing the tracings and collecting the data on 2 acres (0.8 ha).

Black and White Enlargements of Color Aerial Photos—The third method used commercial black and white enlargements of 1:1200 color aerial photos (fig. 1). The enlargements (1:200, approximately 10×) (fig. 2) retained acceptable resolution for locating stumps as small as 3.5 inches (9 cm) in diameter. Enlargements of 9.5- by 9.5-inch (240- by 240-mm) color positives as used in this study were approximately 24 inches by 36 inches (609 by 914 cm). For convenience, these were cut into 8½- by 11-inch (21.5- by 28-cm) pieces and protected from dirt and moisture with self-closing plastic freezer bags. Although the gelatin surface can be treated with special hardners, standard processing provided satisfactory surfaces on which to write with fine-pointed nylon-tip pens having permanent ink. During heavy rains the writing was done within a large, transparent bag; nevertheless the photo surface would soften and care was required to prevent tearing the gelatin. Of even greater inconvenience were ink stoppages due to plugging by the soft gelatin. Many brands and styles of pens were tried but most worked only a few minutes on the softened surface. Most satisfactory was Pilot fineline[2]; it performed well through all seasons. Even very soft lead pencils would tear the softened gelatin; the soft lead markings also smeared badly during field use and transport.

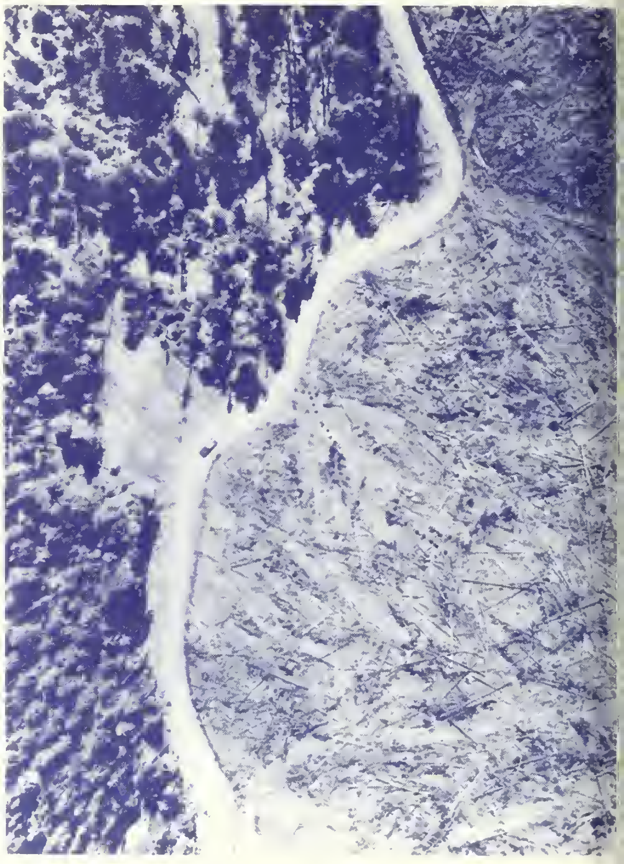


Figure 1—Aerial photo of portion of study site.

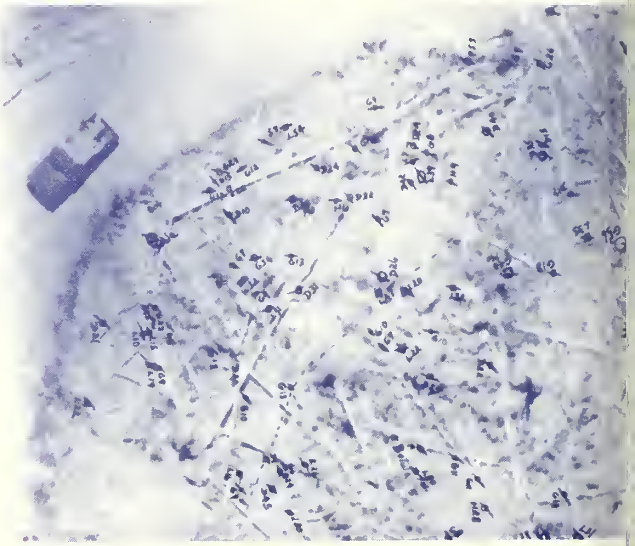


Figure 2—Enlargement (approximately 10×) of aerial photo.

---

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

The scale of 1:200 provided resolution adequate to
scern 3.5-inch (9-cm) diameter stumps and establish their
cation on the photos with little error in true distance
om a neighbor. This method of obtaining permanent
cords of stump locations was found to be the most effi-
ent use of time. Time could be used recording locations,
ecies, size, and cause of decay rather than preparing
etches or tracings. Using this method, permanent
cords were made of 13,800 stumps on 63 acres (25.5 ha)
85 person-days.

UMMARY

The use of black and white enlargements of color
sitive aerial photos as field sheets for recording the loca-
ons of stumps of root-diseased trees was superior to
eehand sketches or tracings of projected images of color
otos. Scale of the image was consistent, and resolution
as adequate for accurate location of stumps as small as
5 inches (9 cm) in diameter. The enlargements could
sily be reassembled, and distances between diseased and
ndiseased neighbors throughout a large experimental
ea could be mapped or compared.

EFERENCES

yler, J. W. An assessment of root diseases in the North-
ern Region. Report 82-21. Missoula, MT: U.S. Depart-
ment of Agriculture, Forest Service, Northern Region;
1982. 12 p.

aubenmire, R.; Daubenmire, J. B. Forest vegetation of
eastern Washington and northern Idaho. Technical
Bulletin 60. Pullman: Washington State University,
Washington Agriculture Experiment Station; 1968.
104 p.

ames, R. L.; Stewart, C. A.; Williams, R. E. Estimating
root disease losses in northern Rocky Mountain national
forests. Canadian Journal of Forest Research. 14:
652-655; 1984.

artridge, A. D.; Miller, D. L. Major wood decays in the
Inland Northwest. University Natural Resource Series
No. 3. Moscow, ID: University of Idaho, Idaho Research
Foundation; 1974. 125 p.

mith, R. S. Root disease-caused losses in the commercial
coniferous forest of the western United States. Report
No. 84-5. Fort Collins, CO: U.S. Department of Agricul-
ture, Forest Service, Forest Pest Management, Methods
Application Group; 1984. 21 p.

hies, W. G.; Hoopes, J. M. Computer mapping of lami-
nated root rot epicenters. In: Forest insect and disease
survey methods, Sec. 3.2.1. Davis, CA: U.S. Department
of Agriculture, Forest Service, Methods Application
Group; 1979: 1-7 and appendixes.

illiams, R. E.; Leaphart, C. D. A system using aerial
photography to estimate area of root disease centers in
forests. Canadian Journal of Forest Research. 8: 214-219;
1978.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

ited States
epartment of
riculture

rest Service

termountain
esearch Station

esearch Note
T-361

tober 1986

Inheritance of the Bark Reaction Resistance Mechanism in *Pinus monticola* Infected by *Cronartium ribicola*

Ray J. Hoff[1]

ABSTRACT

*Necrotic reactions in branch or main stems of western hite pine (*Pinus monticola *Dougl.) caused by infection by he blister rust fungus (*Cronartium ribicola *J.C. Fisch. ex abenh.) are a major mechanism of resistance. Overall, 6 percent of the seedlings eliminated the fungus via this efense system. Heritability based upon crossing family roups averaged 33 percent for three sets of crossing roups. Heritability based upon individuals averaged percent. The largest genetic advance (selected population ompared to the original population before introduction of lister rust) could be made by selecting the average family ut of the plus tree selection group. Moderate gains can be nade just by selecting the best family. A small but significant gain can be made by selecting seedlings within amilies. Several breeding methods are discussed concerng the use of bark reaction resistance in new cultivars of estern white pine.*

EYWORDS: *Pinus monticola, Cronartium ribicola,* blister rust resistance

Resistance to blister rust (caused by *Cronartium ribicola* .C. Fisch. ex Rabenh.) in western white pine (*Pinus monicola* Dougl.) is complex. The complexity is largely due to he varied types of tissues that the fungus grows through rom the needles to the stem.

The fungus can enter the stem directly (Van Arsdel 968), but the usual mode of infection is through stomata f secondary needles (Clinton and McCormick 1919; Patton and Johnson 1967). Symptoms of infection first appear as small yellow spots centered on or near a stomate of a secondary needle within 30 days following inoculation. The fungus produces a large mass of mycelium, called a pseudosclerotium, within the needle directly under the needle spot. It then grows down vascular tissue into the short shoot and thence into the stem. If there is no resistance to stop or impede fungus growth within the needles or stem, the seedling will die within a year or so. Resistance appears to occur very soon after spores of the fungus germinate on the surface of the pine needle and at each change of host tissue, for example leaf mesophyll to leaf vascular system, or leaf vascular system to stem vascular system, etc. Several mechanisms of resistance have been observed (Bingham and others 1971; Hoff and McDonald 1980); undoubtedly there are also a great many genes and/or alleles involved.

Bark reactions were one of the first forms of resistance observed in the white pine-blister rust system (Riker and others 1943). Struckmeyer and Riker (1951) did extensive anatomical studies of these reactions in eastern white pine (*Pinus strobus* L.) and concluded that they were due to the production of a wound-periderm. The more susceptible a seedling, the more extensive mycelium growth was prior to the development of the wound-periderm. No wound-periderm was observed in susceptible seedlings.

Bark reactions have also been reported for sugar pine (*Pinus lambertiana* Dougl.) (Kinloch and Littlefield 1977) and Armand pine (*Pinus armandii* Franch.) (Hoff and McDonald 1972). Boyer (1964) also reported bark reactions for eastern white pine. In a study of 16 white pine species, Hoff and others (1980) reported bark reactions in all species except eastern white pine.

---

[1] Principal plant geneticist located at Intermountain Station's Forestry ciences Laboratory, Moscow, ID.

This publication reports on the heritability of a resistance reaction in the stem—that is, bark reactions—that eliminates the fungus at various times after it has entered the stem.

Because much of the variation in bark reaction data was due to differences between full-sib families, single gene inheritance patterns were sought. No such patterns were found, however, so this character was treated as polygenic, and genetic gains are presented accordingly. This approach is probably more logical because bark reactions do vary in size and time of action in western white pine (fig. 1). The small reaction in figure 1A occurs shortly after the fungus enters the stem, and the reaction in figure 1D occurs 2 to 3 or more years after stem entry.

MATERIALS AND METHODS

Blister-rust-free parent trees were selected for this test. The selections came from throughout the range of western white pine in northern Idaho and western Montana. In all cases, the selected trees were surrounded by blister-rust-killed or heavily infected trees. Frequently, the mortality within the stand was over 90 percent. Lowest was about 40 percent.

The mating design was similar to the factorial design of experiment II of Comstock and Robinson (1952). Bingham and others (1969) discuss assumptions pertaining to this design to breeding for resistance to blister rust in western white pine. The progeny were planted in a randomized complete-block design. Each cross was represented by a 16-seedling plot (two seedlings by eight) in each of six blocks.

In addition, 10 control seed collections were taken from the major rust resistance selection areas. The control cones were either from squirrel caches or from several rust-infected trees. However, these selection areas have had from 40 to 90 percent mortality as a result of blister rust and, therefore, the controls (survivors) probably contain more resistance genes than did the original population prior to blister rust introduction.

Data in this paper were based on the performance of progenies from three groups of testers crossed with selected trees. Each crossing group had four different testers and there were 51 selections in group I, 21 in group II, and 17 in group III. Testers were usually male parents and selected female parents, but in several cases, when there were not enough female strobili on the selected tree, the reciprocal cross was made. But because previous unpublished work indicated no reciprocal or maternal effects, the testers and selections were analyzed without regard to their role as male or female parent.

Test seedlings were inoculated in the fall, usually in September, after their second growing season, that is, a 2-year-old seedling, under conditions outlined for previous tests by Bingham (1972). The inoculum was obtained from heavily infected leaves of *Ribes hudsonianum* var. *petiolare* (Dougl.) Jancz. growing along the west fork of Hobo Creek about 16 km northeast of Clarkia, ID.

Rust inspection was completed as described by Hoff and McDonald (1980). The following data were collected: (1) 9 months after inoculation—presence of needle spots; (2) 12 months after inoculation—presence of needle spots and stem symptoms (normal cankers plus bark reactions); (3) 24, 36, and 48 months after inoculation—presence of stem symptoms.

Analysis of the data was completed after the fourth-yea rust inspection and was based on the number of seedlings that were healthy because of a bark reaction that eliminated the fungus divided by the total number of seedling with stem symptoms, including those that had died due t blister rust, 4 years after inoculation. Those seedlings wit some kind of needle resistance were therefore not included.

The statistical model assumes that the selected trees used as males and females were random samples from th resistant tree populations. This is probably valid for all trees except group I males. These trees had been selecte for higher than average rust resistance from a previous test. They were, however, selected for a high level of tot resistance and not specifically for bark resistance.

The method of analysis followed Bingham and others (1969), Becker and Marsden (1972), and Becker (1971). The formula for the model was:

$$X_{ijk} = \mu + M_i + F_j + (MF)_{ij} + R_k + b_{ijk} + e_{ijk} + d_{ijk}$$

where

X_{ijk} = the transformed proportion of healthy seedlings with bark reactions from the cross of th *i*th male and the *j*th female in the *k*th replication

μ = general mean

M_i = the effect of the *i*th male, $i = 1, 2, \ldots I$

F_j = the effect of the *j*th female, $j = 1, 2, \ldots J$

$(MF)_{ij}$ = the effect of the interactions of the *i*th male and the *j*th female

R_k = the effect of the *k*th replication, $k = 1, 2, \ldots$

b_{ijk} = effect of binomial sampling

e_{ijk} = effect of plot

d_{ijk} = effect of individuals within plots.

Plot means were transformed (arcsin $\sqrt{\text{percent}}$) and missing values were estimated using the method of Steel and Torrie (1960, page 130).

The analysis of variance, expected mean squares, and formulas for estimating the variance components and sta dard errors are shown in table 1.

Heritability was calculated in two ways—one based on individual seedlings, the second on the selection unit, which is the full-sib family unit (Bingham and others 1969). The formulas were as follows, on an individual seedling basis:

$$h^2_{\text{Ind}} = \frac{\sigma^2_A}{\sigma^2_F + \sigma^2_M + \sigma^2_{MF} + \sigma^2_e + \frac{1}{w}\sigma^2_b - \frac{1}{w}\sigma^2_d}$$

where σ^2_A is the additive genetic variance, estimated from $4\,\sigma^2_F$ or σ^2_M. On a family unit basis:

$$h^2_{\text{fam}} = \frac{\sigma^2_A}{\sigma^2_F + \frac{\sigma^2_M}{I} + \frac{\sigma^2_{MF}}{IJ} + \frac{\sigma^2_e + \frac{1}{w}\sigma^2_b - \frac{1}{w}\sigma^2_d}{K}}$$

Table 1—Model for analysis of variance, expected mean squares, variance components, and standard errors

Source of variation	d.f.*	Mean squares	Expectation of mean squares
Replications	$K-1$	MS_R	
Males	$I-1$	MS_M	$\sigma_e^2 + \frac{1}{w}\sigma_b^2 - \frac{1}{w}\sigma_d^2 + K\sigma_{MF}^2 + KJ\sigma_M^2$
Females	$J-1$	MS_F	$\sigma_e^2 + \frac{1}{w}\sigma_b^2 - \frac{1}{w}\sigma_d^2 + K\sigma_{MF}^2 + KI\sigma_F^2$
Male × female	$(I-1)\ (J-1)$	MS_{MF}	$\sigma_e^2 + \frac{1}{w}\sigma_b^2 - \frac{1}{w}\sigma_d^2 + K\sigma_{MF}^2$
Male-female × replications	$(IJ-1)\ (K-1)$	MS_{MFR}	$\sigma_e^2 + \frac{1}{w}\sigma_b^2 - \frac{1}{w}\sigma_d^2$

*I, J, and K = total numbers of testers, candidates, and replications, respectively. Individual variance components are:

$$\sigma_M^2 = \frac{MS_M - MS_{MF}}{KJ} = \text{variance due to males}$$

$$\sigma_F^2 = \frac{MS_F - MS_{MF}}{KI} = \text{variance due to females}$$

$$\sigma_{MF} = \frac{MS_{MF} - MS_{MFR}}{K} = \text{variance due to interaction of males and females}$$

$$\sigma_e^2 - \frac{1}{w}\sigma_d^2 = MS_{MFR} - \frac{1}{w}\sigma_b^2\dagger \quad \sigma_e^2 = \text{variance due to effect of plot}$$

$$\sigma_d^2 = \text{variance due to effect of individuals}$$

$$\sigma_b^2 = \frac{1}{w}821 = \text{variance due to effect of binomial sampling}$$

$$w = \text{harmonic mean number of seedlings}$$

$$\text{S.E.} = \sqrt{\frac{2}{C^2}\sum\frac{MS_n{}^2\dagger\dagger}{fn+2}} = \text{standard errors}$$

†Becker and Marsden 1972.

††C = coefficient of the variance component, MS_n = the nth mean square used to estimate the variance component, and fn = the degrees of freedom of the nth mean square.

where σ_A^2 is equal to 2 σ_F^2, being one-half of the additive genetic variance.

Successive genetic gains were calculated beginning with the amount of resistance in the base populations—that is, all western white pines in the area sampled prior to the ntroduction of blister rust.

The formula for genetic gain is $\Delta G = Sh^2$, where S is the selection differential expressed as the mean of the ndividuals selected for the next generation minus the overall mean. The h^2 on female family was used with this formula to determine the gain from selection.

When the best individuals within the best families were selected, the selection differential was not known. The genetic gain was estimated by the formula $\Delta G = Sh^2\sigma$ phen, where S is the standardized selection differential (Becker 1967, table II) and σ phen is the phenotypic standard deviation. The h^2 based on individuals was used for this gain. The resulting gain was added to the mean calculated from transformed observations, and then converted back to percent. The percent gain was this total minus the percent mean of the population.

RESULTS

Average percentage of healthy seedlings with bark reactions ranged from 20.2 to 29.4 for male groups. The range for all females was 8.0 to 44.2 percent. Controls averaged 14.2 percent (table 2).

Analysis of variance of the plot values, transformed (arcsin $\sqrt{\text{percent}}$), is shown in table 3. Mean squares for females were significant in all three crossing groups. Mean squares for males were significant for group III. Variance components are shown in table 4 with standard errors.

Table 5 displays heritabilities based on a selection unit basis (full-sib family) and on an individual basis. The male × female interaction estimates one-quarter of the dominance and one-eighth of the epistatic variance, so the values in table 4, group I and II, cannot be negative in a biological sense. In determining heritabilities, these values were assumed to be zero.

Genetic gains from three main sources could be made: (1) increase in resistance over the base population (base population here is defined as the population prior to the

Table 2—Results of artificial inoculation of seedlings in three western white pine crossing groups

Component			Crossing groups	
		I	II	III
Average seedling number/plot		8.43	9.24	8.04
Total seedlings		10,318	4,657	3,280
Average percent healthy				
Males	a	32.2	19.7	45.3
	b	29.8	19.1	27.3
	c	29.3	18.6	24.3
	d	26.3	17.6	20.8
Group average, percent healthy		29.4	20.2	29.4
Range of candidates, percent healthy		43.1-14.9	32.7-8.0	44.2-19.2
Controls, percent healthy	Average		14.5	
	Range		32.3-8.5	

Table 3—Analysis of variance of transformed data

	Group I		Group II		Group III	
Source of variation	df†	ms	df†	ms	df†	ms
Replications	5	8,599.07**	5	3,669.22**	5	2,052.30**
Males	3	385.18	3	616.52	3	4,063.69**
Females	50	539.84**	20	612.31**	16	526.10*
Male × female	150	277.98	60	260.23	48	397.15
Male – female × replications	1,009	326.32	412	264.99	331	332.44

†Degrees of freedom were reduced for missing plots as follows: 6 in group I, 3 in group II, 4 in group III.
*Significant at the 10 percent level of probability.
**Significant at the 1 percent level of probability.

Table 4—Variance components for percent bark reactions in three western white pine crossing groups

Variance factors and harmonic mean	Group I	Group II	Group III
σ^2_M	0.35 ± 0.80*	2.83 ± 1.27*	35.95 ± 25.20*
σ^2_F	10.91 ± 4.61	14.67 ± 3.25	5.37 ± 8.02
σ^2_{MF}	−8.06 ± 5.84	−4.76 ± 3.61	10.78 ± 13.92
$\sigma^2_e - \frac{1}{w}\sigma^2_d$	183.79	140.22	167.91
$\frac{1}{w}\sigma^2_b$	142.53	124.77	164.58
Harmonic mean, *w*	5.76	6.58	4.99

*Standard error.

Table 5—Estimates of genetic variance and heritabilities of bark reactions in three western white pine crossing groups

	Crossing group								
	I			II			III		
Populations	σ_A^2	σ_D^2	h^2	σ_A^2	σ_D^2	h^2	σ_A^2	σ_D^2	h^2
Individual male	1.40	0	0.1 ± 0.3*	11.32	0	1.2 ± 1.3*	143.80	43.12	14.1 ± 9.7*
Individual female	43.64	0	4.3 ± 1.8	58.68	0	6.0 ± 3.3	21.48	43.12	2.1 ± 3.1
Selection unit (full-sib family)	21.82		0.33 ± 0.14	29.34		0.49 ± 0.27	10.75		0.15 ± 0.23

*Standard error.

ntroduction of blister rust) by using all families; (2) increase in resistance through the selection of best families; and (3) selection of individuals within best families.

The gain in resistance over the base population of an average family in group I is expected to be 29.4 percent. This could be an overestimate because the males were selected for a high level of total resistance that probably ncluded some bark resistance. For group II the gain is estimated as 20.2 percent and for group III, 29.4 percent.

The second increment of gain is the selection of the best families. This gain ranged from 2.3 to 6.2 percent when the five best families were selected. Means for the top 20 percent female families are listed in table 6. The gains are shown in table 7 under ΔG_F for various selection evels.

The third gain comes from selecting individuals within the best family and is listed under ΔG_{Ind} in table 7. This gain ranged from 0.9 to 2.7 percent within the top five families.

Total gain is the sum of the three gains, and they are isted under total gain above base in table 7. For the top five families, the gains were 35.4 percent for group I, 29.1 percent for group II, and 32.6 percent for group III.

Table 6—Bark resistance of the top 20 percent of selected western white pine trees

Group	Female family identification	Overall mean
		Percent
I	32	43.1
	260	42.5
	95	41.3
	115	40.5
	194	40.4
	274	39.3
	31	39.0
	220	38.7
	258	38.6
	34	37.2
II	247	32.7
	133	32.3
	132	28.5
	281	27.6
	173	26.5
III	373	44.2
	326	39.7
	348	38.6
	312	36.1
	100	35.5

Table 7—Expected genetic gain (percent) from crossing superior families or superior seedlings of these families at various selection intensities

	Group I			Group II			Group III		
Families selected	ΔG_F†	ΔG_{Ind}*	Total gain** above base	ΔG_F	ΔG_{Ind}	Total gain above base	ΔG_F	ΔG_{Ind}	Total gain above base
5	4.3	1.7	34.4	6.2	2.7	28.1	2.3	0.9	31.6
10	4.1	1.9	34.4	6.1	2.7	28.1	1.9	.9	31.2
25	3.5	1.9	33.8	4.6	2.9	26.7	1.6	.9	30.9
50	2.1	2.1	32.6	2.7	3.0	24.9	1.1	.9	30.4

†Genetic gain from selective mating of selected families.

*Genetic gain from selection and mating of seedlings from selected families.

**Includes genetic gain of average family over base population (1 percent resistance): 28.4 for group I; 19.2 for group II; and 28.4 for group III.

DISCUSSION

An average of 26 percent of the seedlings, over all three groups, produced necrotic reactions in stem tissues that prevented the fungus from further growth (table 2). On the other hand nearly 15 percent of the control seedlings also developed bark reactions that eliminated the fungus. So what is the gain in resistance? Bingham and others (1960) used the control data to adjust the level of resistance in the selected population. At that time total resistance of the controls was 5.3 percent. Total resistance (needle resistance plus bark resistance) of the controls in our test was 22.8 percent, reflecting an increase in resistance that is associated with the increase in mortality of white pine trees within the natural stands.

The controls cited in the present paper were survivors i stands that have had as much as 93 percent mortality due to blister rust. Therefore, they probably carry several resistance genes—possibly not enough to survive to rotation, but enough so that when crossed with other survivors, including the resistance candidates in the stand, a relatively high level of resistance is expressed in their progeny. The question really centers on the amount of resistance in original population, that is, the population before blister rust was introduced. In an experimental planting of 500 3-year-old western white pine, Mielke (1943) reported that 6 years after planting only nine seedlings were alive, but five were infected; and within another 2 years all were infected. One of the stands that

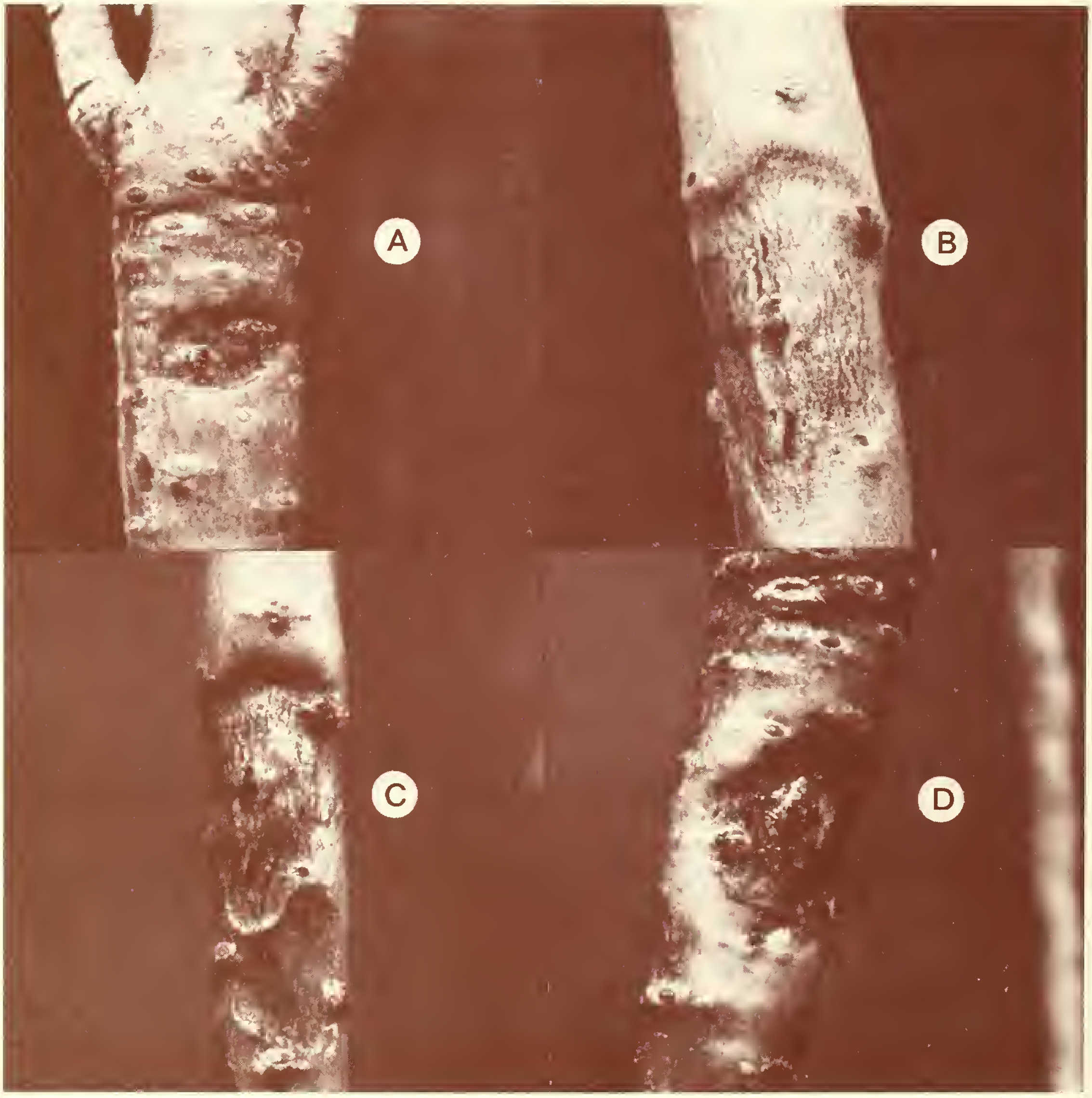


Figure 1—Bark reactions in western white pine in response to blister rust: (A) Reaction soon after fungus enters stem. (B and C) Reaction after fungus has grown in stem for a while. (D) With this reaction fungus growth and reaction alternate—that is, the fungus grows followed by a bark reaction that does not completely kill the fungus.

roduced seed for this bark reaction study was first in- ected in 1937 when about 15 years old. When the seed as collected for this test—1964—the stand had undergone 3 percent mortality (345/371 trees per acre) due to blister ust. By 1984, mortality was 98 percent and based on the ondition of remaining trees will likely increase to over 9 percent in 2 to 3 years. Therefore, for this study, resis- ance in the base population was fixed at 1 percent. Still, his is a conservative figure to use for bark resistance ecause the 1 percent includes all mechanisms of esistance.

The differences among the full-sib families leave little oubt that substantial gains can be made after just one election cycle. This original selection was a combination f natural selection by infecting and killing of the most usceptible trees and of artificial selection by our choosing ees with no infections among the survivors. Stem esistance was increased from 1 percent (resistance in the ase population) to about 25 percent—averaged over the hree groups—with just this one cycle of selection.

Predicting additional gain for future selection was not early as good. Table 7 indicates that an average of just percent could be made by choosing the best five families. ain by selecting the best individuals resulted in an in- rease of less than 2 percent. Several reasons for these w additional gains are evident:

1. The low selection differential; there were only 89 can- idate trees, and these were separated into three breeding nits (selection groups). In surveys of natural stands ingham (1983) concluded that in the high hazard stands tree in 10,000 was not infected; thus the first round of election was based on very high selection differential.
2. In each family seedlings were few and varied in umber. Seedlings with needle resistance—resistance fac- ors that function before stem resistance (Bingham and thers 1971)—were removed from the data set. Because eedle resistance is highly heritable some families were eft with only a few individuals, some with many.
3. Variation in bark resistance is high. Bark reaction aried from small to very large (fig. 1). The fungus was ften killed quickly, whereas at other times the fungus ngered on, disappeared, and sometimes reappeared. Then oo, some seedlings showed a well-defined bark reaction long with a typical susceptible reaction. The reactions ere often separated; therefore, it was obvious that they ame from separate primary infections, namely, needle pots. This is typical of a differential reaction that occurs hen there is genetic variation in the fungus. This results n confusion and error in the resistance rating system.
4. The infection load was uneven. Although all seedlings hat were included in this study were infected, some had any separate primary infections (100 or more needle pots) whereas other seedlings had only one.

Despite difficulties with this data, the relatively large ain that can be made by just selecting average families ould seem to justify using stem resistance in seed rchards. Choosing a portion of the best families may, ith luck, even provide a little more gain. The level of tem resistance is not high enough to use by itself for ost planting sites, and should not be used singly anyway because of the threat of new blister rust races, but when used in combination with other mechanisms of resistance it will likely provide adequate levels of resistance. At the same time, the combination of several resistance factors would provide defense against new races of blister rust.

For advanced breeding programs much more knowledge is needed. Two important objectives must be addressed: (1) to determine if the observed bark reaction differences reflect different mechanisms and/or genes; (2) to determine the relationship of present observed races of the blister rust fungus with the various bark reaction types.

ACKNOWLEDGMENTS

I gratefully acknowledge the thoughtful criticism of Dr. J. Kraus, Forest Service, U.S. Department of Agriculture, Macon, GA; Dr. R. Blair, Potlatch Corporation, Lewiston, ID; Dr. G. D. Booth, Forest Service, Ogden, UT; and Dr. B. B. Kinloch, Jr., Forest Service, Berkeley, CA.

REFERENCES

Becker, W. A. Manual of procedure in quantitative genetics. 2d ed. Pullman, WA: Washington State University; 1967. 125 p.

Becker, W. A. A quantitative genetic analysis of blister rust resistance in western white pine. In: Genetics lectures, vol. 2. Corvallis, OR: Oregon State University Press; 1971: 91-99.

Becker, W. A.; Marsden, M. A. Estimation of heritability and selection gain for blister rust resistance in western white pine. In: Biology of rust resistance in forest trees. Miscellaneous Publication 1221. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972: 397-409.

Bingham, R. T. Artificial inoculation of large numbers of *Pinus monticola* seedlings with *Cronartium ribicola*. In: Biology of rust resistance in forest trees. Miscellaneous Publication 1221. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972: 357-372.

Bingham, R. T. Blister rust resistant western white pine for the Inland Empire. General Technical Report INT-146. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 45 p.

Bingham, R. T.; Hoff, R. J.; McDonald, G. I. Disease resistance in forest trees. Annual Review of Phytopathology. 9: 433-452; 1971.

Bingham, R. T.; Olson, R. J.; Becker, W. A.; Marsden, M. A. Breeding blister rust resistant western white pine. V. Estimates of heritability, combining ability, and genetic advance based on tester matings. Silvae Genetica. 18: 28-38; 1969.

Bingham, R. T.; Squillace, A. W.; Wright, J. W. Breeding blister rust resistant western white pine. II. First results of progeny tests including preliminary estimates of heritability and rate of improvement. Silvae Genetica. 9: 33-41; 1960.

Boyer, M. G. The incidence of apparent recovery from blister rust in white pine seedlings from resistant parents. In: Proceedings, 9th committee on forest tree breeding in Canada. Maple, ON: Forest Entomology and Pathology Branch, Forest Pathology Laboratory; 1964: 13.

Clinton, C. P.; McCormick, F. A. Infection experiments of *Pinus strobus* with *Cronartium ribicola*. Bulletin 214. New Haven, CT: Connecticut Agricultural Experimental Station; 1919: 428-459.

Comstock, R. E.; Robinson, H. F. Estimation of average dominance of genes. In: Gowen, J. W., ed. Heterosis. Ames, IA: Iowa State College Press; 1952: 494-516.

Hoff, R. J.; McDonald, G. I. Resistance of *Pinus armandii* to *Cronartium ribicola*. Canadian Journal of Forest Research. 2: 303-307; 1972.

Hoff, R. J.; McDonald, G. I. Improving rust-resistant strains of inland western white pine. Research Paper INT-245. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 13 p.

Hoff, R. J.; Bingham, R. T.; McDonald, G. I. Relative blister rust resistance of white pines. European Journal of Forest Pathology. 10: 307-316; 1980.

Hoff, R. J.; McDonald, G. I.; Bingham, R. T. Mass selection for blister rust resistance: a method for natural regeneration of western white pine. Research Note INT-202. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 11 p.

Kinloch, B. B., Jr.; Littlefield, J. L. White pine blister rust: hypersensitive resistance in sugar pine. Canadian Journa of Botany. 55: 1148-1155; 1977.

Mielke, J. L. White pine blister rust in western North America. Bulletin 52. New Haven, CT: Yale University School of Forestry; 1943. 155 p.

Patton, R. F.; Johnson, D. W. Mode of penetration of needles of eastern white pine by *Cronartium ribicola*. Phytopathology. 60: 977-982; 1967.

Riker, A. J.; Kouba, T. F.; Brener, W. H.; Byam, L. E. White pine selections tested for resistance to blister rust. Journal of Forestry. 41: 753-760; 1943.

Steel, R. G. D.; Torrie, J. H. Principles and procedures of statistics. New York: McGraw-Hill; 1960. 481 p.

Struckmeyer, B. E.; Riker, A. J. Wound-periderm formatio in white pine trees resistant to blister rust. Phytopathology. 41: 276-281; 1951.

Van Arsdel, E. P. Stem and needle inoculations of eastern white pine with the blister rust fungus. Phytopathology. 58: 512-518; 1968.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

☆ U.S. GOVERNMENT PRINTING OFFICE: 1986—676-039/41,022 REGION NO. 8

nited States
epartment of
griculture

orest Service

ntermountain
esearch Station

esearch Note
NT-362

ovember 1986

Small Mammal Responses to Diameter-Cut Logging in an Idaho Douglas-fir Forest

Dean E. Medin

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Small Mammal Responses to Diameter-Cut Logging in an Idaho Douglas-fir Forest

Dean E. Medin[1]

BSTRACT

elative small mammal populations were estimated on
ged and unlogged plots from 1975 (first-year prelogging)
ough 1979 (third-year postlogging) by using live-trapping
l mark-recapture methods. Three species made up
percent of 698 individual animals caught: deer mice
romyscus maniculatus), *yellow-pine chipmunks* (Tamias
oenus), *and Gapper's red-backed voles* (Clethrionomys
peri). *Deer mice populations were similar on both*
ged and unlogged plots. Numbers of yellow-pine chip-
nks increased on logged sites. Red-backed voles disap-
red from the small mammal community after logging.
er species, including the golden-mantled ground squirrel
ermophilus lateralis) *and shrews* (Sorex *spp.), were*
pped irregularly and in smaller numbers.

YWORDS: diameter-limit cut, *Pseudotsuga menziesii*, helicopter logging, *Peromyscus maniculatus*, *Tamias amoenus*, *Clethrionomys gapperi*

TRODUCTION

mall mammals are an important faunal component of
st ecosystems. They may reduce forest regeneration
ough destruction of seeds and seedlings (Gashwiler
7; Hooven 1971). Mice, chipmunks, and voles are
able consumers of conifer seed (Radvanyi 1973). Pocket
hers damage and destroy seedlings and may contribute
he death of trees as late as 10 years after planting
ouch 1976). On the other hand, small mammals con-
e significant numbers of forest insects (Van Horne
2) and are themselves consumed by mammalian,
ilian, and avian predators.

gging the forest alters habitat for small mammals.
ulations of some species may increase while others
ine in postlogging environments (Gashwiler 1970;
ven and Black 1976).

y purpose is to report short-term changes in species
position and relative abundance of small mammals
wing diameter-cut logging in a Douglas-fir (*Pseudo-*
a menziesii) forest in west-central Idaho. My data
collected as part of a study of the environmental
ts of logging and associated road construction in the
o batholith, a large region (16,000 mi^2) characterized by steep topography and shallow, erodible soils (Megahan 1983). A diameter-limit cut, defined as the removal of all merchantable trees above a specified diameter (Ford-Robertson 1971), is one of several timber harvesting methods currently being evaluated for their multiple impacts on the forest ecosystem.

STUDY AREA

This research was conducted on two experimental watersheds of 403 acres (SC-6) and 319 acres (SC-3) in the Silver Creek drainage, a tributary of the Middle Fork of the Payette River in Valley County, ID. These third-order watersheds range in elevation from 4,500 to 6,700 ft and are representative of forested drainages found in mid-elevation, nonglaciated landscapes of the Idaho batholith. The slopes are steep, dissected, and face southeast. Annual precipitation averages about 39 inches, much of it falling as snow (Clayton and Kennedy 1985).

Douglas-fir and ponderosa pine (*Pinus ponderosa*) are the dominant overstory trees, with scattered stands of grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*). Mallow ninebark (*Physocarpus malvaceous*) and white spiraea (*Spiraea betulifolia*) normally dominate the shrubby undergrowth. Western serviceberry (*Amelanchier alnifolia*), Rocky Mountain maple (*Acer glabrum*), snowberry (*Symphoricarpos* spp.), and common chokecherry (*Prunus virginiana*) are often present. Many forbs and graminoids occupy the ground layer.

Two habitat types (Steele and others 1981) are mainly represented: Douglas-fir/ninebark, ponderosa pine phase, and Douglas-fir/white spiraea, ponderosa pine phase. Experimental watersheds include elements of both habitat types. Plant names in the paper follow Hitchcock and Cronquist (1973).

LOGGING PROCEDURE

Trees on watershed SC-6 were cut to a 10-inch minimum diameter at breast height (d.b.h.) in three separate, well-spaced cutting units. Watershed SC-3 served as a nearby unlogged control. The logged units, topographically defined and irregularly elongated, were 20, 22, and 45 acres. Uncut buffer zones bordered the cutting units and averaged 50 ft to first-order or second-order stream channels, and 100 ft to the third-order (main) stream channel. Logs were yarded by helicopter to minimize site damage. Logging began in September and was completed in November 1976. Slash was lopped, scattered, and broadcast burned. About 80 percent of the slash was burned.

---

thor is a research wildlife biologist, Intermountain Research
on, Forest Service, U.S. Department of Agriculture, Boise, ID.

STUDY METHODS

Amounts of overstory and understory vegetation were determined, and live traps were used at the study sites. Vegetation study measurements are presented here in the original metrics.

Overstory Vegetation

A surveyed and marked grid system of 200 by 200 m was superimposed on the experimental watersheds. Overstory (tree) data were derived from nine equidistant sample points in each grid square within cutting unit boundaries. From each sample point, 22.1-m lines were measured in each cardinal direction. Ten milacre quadrats were established along each line to record sapling and pole frequency and density by diameter class. The center of a variable-radius plot was located at the midpoint of each line. Height, d.b.h., and other data were measured for each sample tree selected using an angle gauge (Geier-Hayes and Ryker 1983).

Understory Vegetation

Sampling procedures for measuring understory vegetation followed Daubenmire and Daubenmire (1968). A macroplot 15 by 25 m was located at each of four sampling sites within each cutting unit. Two 25-m transects were placed perpendicular to the short axis of the macroplot. Forb and graminoid canopy coverage data (Daubenmire 1959) were estimated from 50 microplots of 20 by 50 cm each, placed at 1-m intervals along the transects. Fifty 1-m^2 plots placed contiguous to the microplots were used to estimate shrub canopy coverage. Canopy coverage was recorded as the midpoint of one of seven coverage classes (0-0.5, 0.5-5, 5-25, 25-50, 50-75, 75-95, and 95-100 percent).

Small Mammals

Two permanently marked 5.6-acre trapping grids were established before logging to estimate small mammal populations. One grid was located near the center of the largest cutting unit in the watershed to be logged (SC-6), and the other in the unlogged control watershed (SC-3). Each grid measured 495 by 495 ft and consisted of 100 trap positions regularly spaced at 55-ft intervals in 10 rows and 10 columns. One metal Tomahawk[2] live trap, 3 by 3 by 10 inches, was placed at each position. Traps were baited with a mixture of cracked corn, wheat, and oats. Surgical cotton was placed in each trap for insulation to minimize death from exposure. Captured animals were ear-tagged with Monel fingerling tags and released at the point of capture. Trapping was conducted annually for a 6-night period on each grid in August and early September from 1975 (first-year prelogging) through 1979 (third-year postlogging).

Populations of the deer mouse (*Peromyscus maniculatus*), yellow-pine chipmunk (*Tamias amoenus*), and Gapper's red-backed vole (*Clethrionomys gapperi*) were estimated by means of the mark-recapture method and t Schnabel estimator (as described in Overton and Davis 1969). The effective trapping area was considered to be the grid plus a strip whose width was equal to half the average range length added to each side. Range length was determined by the "adjusted range length" method described by Stickel (1954). These methods provide imprecise estimates of total populations. Therefore, I rega the small mammal densities reported in this study as relative rather than absolute.

As an additional indicator of relative abundance, the number of individual animals caught in each 6-night trapping period was used for deer mice, yellow-pine chipmunks, red-backed voles, golden-mantled ground squirre (*Spermophilus lateralis*), and other animals that were trapped in small numbers.

Significant differences (P<0.10) in the total number of animals captured before and after logging were determined for each species by analysis of variance. Square root transformations of the count data were made befo each analysis was performed. Because this study was n replicated, it was necessary to make the assumption of dependence among yearly observations in order to perf an analysis. Confidence limit calculations for estimates species density followed Overton and Davis (1969).

RESULTS AND DISCUSSION

Not surprisingly, the vegetation during this study differed between the logged and unlogged sites. But small mammal populations differed not in number, but rather composition.

Vegetation

Stand density on the small mammal study area (cutti unit) averaged 125 stems per acre before logging (table). A fourth of these were large (>10 inches d.b.h.) Dougla firs and ponderosa pines. Trees remaining after logging mostly pole-sized (<10 inches d.b.h.), averaged 73 stem per acre. Uncut trees were distributed in patches of hi density imposed upon a general distribution of lower de sity. Few dominants or large standing snags remained after logging. Stand basal area was reduced 76 percent logging. Stand volume was reduced nearly 98 percent. Much of the woody debris on the forest floor was destroyed by slash burning, although a few of the larg fallen trees and most of the stumps remained. The soil surface was blackened with a layer of ash for more tha year after the slash was burned. Unburned slash debri was irregularly distributed over the logged area.

Shrubs were the major feature of the understory vege tion (table 1). Shrub canopy coverage values were redu by logging and slash burning. Total shrub cover two gr ing seasons after logging was about half that of the

---

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

e 1—Features of the vegetation on small mammal study area before and after logging, west-central Idaho, 1976 to 1978. Values for understory vegetation (shrubs, graminoids, forbs, and annuals) are expressed as percentage canopy cover[1]

Feature	Pre-logging	Post-logging
s		
sal area (ft²/acre)	90	22
nd volume (ft³/acre)	3,013	43
e density (No./acre)[2]	29.3	1.9
le density (No./acre)[3]	96	71
bs		
stern serviceberry (*Amelanchier alnifolia*)	1.2	1.0
owbrush ceanothus (*Ceanothus velutinus*)	1.4	.9
llow ninebark (*Physocarpus malvaceus*)	21.1	8.8
mmon chokecherry (*Prunus virginiana*)	3.2	2.1
ite spiraea (*Spiraea betulifolia*)	14.0	7.9
ers	5.1	4.0
tal	46.0	24.7
inoids		
sedge (*Carex geyeri*)	3.8	3.3
egrass (*Calamagrostis rubescens*)	11.1	13.1
hers	0	1.6
tal	14.9	18.0
s		
art-leaf arnica (*Arnica cordifolia*)	3.2	4.5
gleaf sandwort (*Arenaria macrophylla*)	3.1	1.9
avine (*Lathyrus* spp.)	16.2	8.9
hers	3.7	7.0
tal	26.2	22.3
uals		
nall-flowered collinsia (*Collinsia parviflora*)	0	3.4
rge-flowered collomia (*Collomia grandiflora*)	<.1	0
ner's lettuce (*Montia perfoliata*)	0	.7
hers	0	.7
tal	<.1	4.8

elogging sampling was conducted in 1976; postlogging ampling was conducted in 1977; postlogging understory ling was conducted in 1978. Data are from Geier-Hayes yker (1983). Measures of variation for these data are not ble.

ees >10 inches d.b.h.

ees 3 to 10 inches d.b.h.

prelogging level. Mallow ninebark and white spiraea, dominant in the unlogged forest, remained so after logging but at reduced levels. Western serviceberry, snowbrush ceanothus (*Ceanothus velutinus*), and common chokecherry were proportionately more important on the logged area.

Herbaceous vegetation recovered more quickly than the shrubs and approached coverage values found in the unlogged forest within 2 years after logging. Of the herbaceous perennials, pinegrass (*Calamagrostis rubescens*) and heart-leaf arnica (*Arnica cordifolia*) increased the most. Annuals, principally small-flowered collinsia (*Collinsia parviflora*), formed an important herbaceous component of the understory vegetation in the logged forest. Shrubs and herbs had a combined canopy coverage of 87 percent before logging and 70 percent 2 years after logging.

Small Mammals

During the 5-year study, 698 individual animals were trapped (table 2). Of the 10 species caught, deer mice, yellow-pine chipmunks, and Gapper's red-backed voles accounted for 93 percent of the total. Deer mice and yellow-pine chipmunks were trapped each year on both logged and unlogged plots. Golden-mantled ground squirrels were caught only in the cutting unit; none were observed in the control area. Other species were trapped irregularly and in smaller numbers. There were pronounced differences in the number of small mammals trapped each year in both the logged and unlogged forest.

Deer Mouse—Populations of deer mice fluctuated irregularly on the unlogged control area (fig. 1). Densities in the unlogged forest ranged from 0.2 to 5.0 animals per acre during the study. Annual fluctuations were less pronounced in the logged forest, ranging from 0.9 to 2.5 deer mice per acre. Postlogging populations of deer mice were similar on both logged and unlogged plots. A clear indication of dissimilar density was found only in the third year after logging when estimated deer mouse density on the unlogged plot was twice that of the logged plot (fig. 1). A parallel pattern of response is suggested when trapping results are expressed as the number of individual deer mice captured each year (table 2). However, no significant differences (P>0.10) were found in the number of individual deer mice caught on logged and unlogged plots in either the prelogging or postlogging periods (table 3).

These results contrast with similar studies conducted elsewhere in the West where greater numbers of deer mice were found on logged areas when compared with nearby unlogged habitats (Gashwiler 1970; Halvorson 1982; Hooven and Black 1976; Tevis 1956; Van Horne 1981). A few, however, have reported either similar or higher deer mouse populations in uncut forests when compared with recently logged areas (Harris 1968; Petticrew

Table 2—Number of individual animals caught annually during a 6-night trapping period on logged and unlogged study plots, west-central Idaho, 1975 to 1979

Species	Number of individuals									
	Prelogging		Postlogging[1]			Unlogged (control)				
	1975	1976	1977	1978	1979	1975	1976	1977	1978	1979
Deer mouse (*Peromyscus maniculatus*)	36	21	12	11	35	20	32	4	13	58
Yellow-pine chipmunk (*Tamias amoenus*)	27	33	33	54	65	33	30	8	12	36
Gapper's red-backed vole (*Clethrionomys gapperi*)	2	6	0	0	0	15	9	20	6	18
Golden-mantled ground squirrel (*Spermophilus lateralis*)	2	0	4	5	2	0	0	0	0	0
Others[2]	4	3	0	1	5	5	4	2	6	6
Total	71	63	49	71	107	73	75	34	37	118

[1] Logging began in September and was completed in November 1976. Slash was burned in February 1977.

[2] Other animals include shrews (*Sorex* spp.), northern flying squirrel (*Glaucomys sabrinus*), long-tailed weasel (*Mustela frenata*), northern pocket gopher (*Thomomys talpoides*), western jumping mouse (*Zapus princeps*), and water vole (*Arvicola richardsoni*).

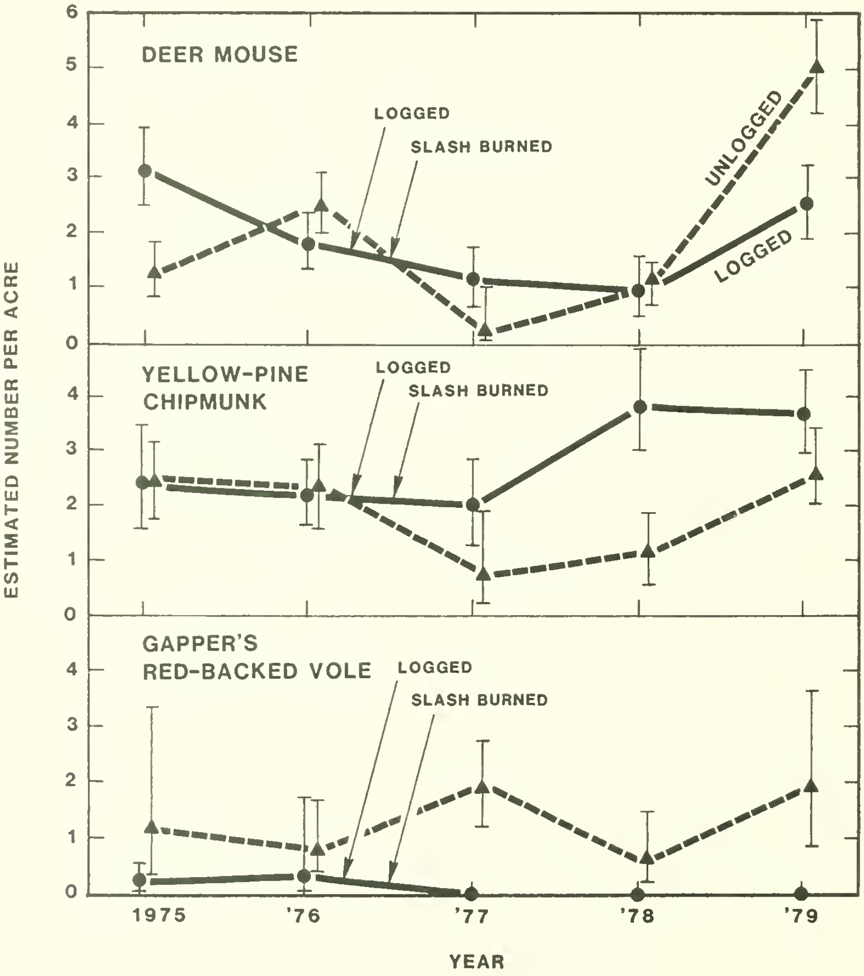


Figure 1—Estimated densities of deer mice, yellow-pine chipmunks, and Gapper's red-backed voles on logged and unlogged study plots, 1975 to 1979. Confidence limits are at the 95 percent level.

Table 3—Number of individual animals of each species caught on logged and unlogged plots before and after logging, west-central Idaho, 1975 to 1979

	Prelogging (1975-1976)			Postlogging (1977-1979)		
Species	Logged plot	Unlogged plot	Probability[1]	Logged plot	Unlogged plot	Probability[1]
Deer mouse	57	52	0.911	58	75	0.916
Yellow-pine chipmunk	60	63	.911	152	56	.024
Gapper's red-backed vole	8	24	.091	0	44	.001
Golden-mantled ground squirrel	2	0	.188	11	0	.003
Others	7	9	.745	6	14	.141

[1] Probability associated with the statistical test. Small probabilities suggest a significant difference in logged versus unlogged plots.

Sadleir 1974; Sullivan 1979). Different responses of
mice to logging may be partly a result of the amount
over remaining on logged areas, or variations in the
lability of food. Or, as Sullivan (1979) suggests,
ntly logged areas may be acting as dispersal sinks for
mice.

ellow-pine Chipmunk—Rickard (1960) found the
ow-pine chipmunk distributed throughout the con-
ous forest zones of eastern Washington and adjacent
hern Idaho. But little is known about the effects of
ing on this locally common small mammal. More has
reported on the Townsend's chipmunk (*Tamias*
nsendii) to the west (Gashwiler 1970; Hooven and
k 1976; Tevis 1956) and the red-tailed chipmunk
nias ruficaudus) to the north (Halvorson 1982;
irez and Hornocker 1981; Scrivner and Smith 1984).
this study, estimated yellow-pine chipmunk densities
ged from 0.8 to 2.7 animals per acre in the unlogged
st (fig. 1). Prelogging densities on the control area and
logged plot were nearly identical. Diameter-cut logging
lted in a twofold increase in estimated density, reach-
a high of 3.9 animals per acre in the second year after
ing. The yellow-pine chipmunk was the most com-
ly trapped small mammal in the logged forest
le 2). The number of individual yellow-pine chipmunks
ped after logging was significantly higher (P<0.10) on
logged plot than on the unlogged plot (table 3). The
ies apparently has a wide variation in habitat use.
ow-pine chipmunks were an important component of
ll mammal communities on clearcuts in southwestern
gon (Black and Hooven 1974).

apper's Red-backed Vole—Estimated densities of the
backed vole in the unlogged forest ranged from 0.7 to
animals per acre (fig. 1). Although prelogging popula-
s were relatively low on the area to be logged, the red-
ked vole disappeared from the small mammal commun-
after logging and slash burning (table 2). None were
ped in the logged forest for the remainder of the
y (table 3). Similar patterns of decrease in the abun-
e of red-backed voles after logging have been ob-
ed in Douglas-fir forests of Oregon (Gashwiler 1970;
ven and Black 1976) and California (Tevis 1956), in
(*Larix occidentalis*)/Douglas-fir forests of Montana
vorson 1982), and in subalpine fir (*Abies lasiocarpa*)
sts of northwestern Montana (Ramirez and Hornocker
1981). Red-backed voles apparently prefer mesic habitats in coniferous, deciduous, and mixed forests with an abundant litter of stumps, rotting logs, and exposed roots (Merritt 1981). Ure and Maser (1982) suggested that a dependence on ectomycorrhizal fungi as a source of food by western red-backed voles may account for their disappearance from deforested sites.

Other Species—Other small mammals were either captured or observed in the Douglas-fir forest. The golden-mantled ground squirrel was trapped irregularly and in small numbers both before and after diameter-cut logging (table 2). None were caught on the unlogged control. Shrews (*Sorex* spp.) were captured infrequently on both logged and unlogged sites. Incidental numbers of the northern flying squirrel (*Glaucomys sabrinus*), long-tailed weasel (*Mustela frenata*), western jumping mouse (*Zapus princeps*), water vole (*Arvicola richardsoni*), and northern pocket gopher (*Thomomys talpoides*) were trapped. Red squirrels (*Tamiasciurus hudsonicus*), common in the unlogged forest, were infrequently observed on the logged area. The trapping methods used in this study are not an effective means of determining the numbers of most of these species.

Summary—The total number of small mammals captured each year on logged sites was about the same as the number caught on unlogged sites. But there was a pronounced compositional change in the small mammal community following diameter-cut logging. Deer mice, numerically codominant with yellow-pine chipmunks in the unlogged forest, made up only a fourth of the number of small mammal captures in the logged forest. Yellow-pine chipmunks accounted for two-thirds of the animals captured on the logged plot; they were the most commonly trapped small mammal on logged sites. Red-backed voles, uncommon on the cut area, were not found after logging. Other species, including shrews and golden-mantled ground squirrels, were infrequently trapped.

ACKNOWLEDGMENTS

Author acknowledges James R. Groves, Robert Jordan, Stanley K. Baker, Sheila Donovan, Daniel A. Dolezal, Walter F. Megahan, James L. Clayton, Timothy L. Mosko, Dale O. Hall, and Russell A. Ryker for their contributions to this study.

REFERENCES

Black, Hugh C.; Hooven, Edward F. Response of small-mammal communities to habitat changes in western Oregon. In: Black, Hugh C., ed. Wildlife and forest management in the Pacific Northwest. Corvallis, OR: Oregon State University; 1974: 177-186.

Clayton, James L.; Kennedy, Debora A. Nutrient losses from timber harvest in the Idaho batholith. Soil Science Society of America Journal. 49(4): 1041-1049; 1985.

Crouch, Glenn L. Wild animal damage to forests in the United States and Canada. In: Proceedings, 16th IUFRO World Congress, Division II, Norway; 1976: 468-478.

Daubenmire, R. A canopy-coverage method of vegetational analysis. Northwest Science. 33(1): 43-64; 1959.

Daubenmire, R.; Daubenmire, Jean B. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington State University, Agricultural Experiment Station; 1968. 104 p.

Ford-Robertson, F. C., ed. Terminology of forest science, technology practice and products. Washington, DC: Society of American Foresters; 1971. 349 p.

Gashwiler, Jay S. Conifer seed survival in a western Oregon clearcut. Ecology. 48(3): 431-438; 1967.

Gashwiler, Jay S. Plant and mammal changes on a clearcut in west-central Oregon. Ecology. 51(6): 1018-1026; 1970.

Geier-Hayes, Kathleen; Ryker, Russell A. Vegetation response to helicopter logging, Silver Creek watershed, Idaho: progress report. 1983. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID.

Halvorson, Curtis H. Rodent occurrence, habitat disturbance, and seed fall in a larch-fir forest. Ecology. 63(2): 423-433; 1982.

Harris, A. S. Small mammals and natural reforestation in southeast Alaska. Research Note PNW-75. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1968. 7 p.

Hitchcock, C. Leo; Cronquist, Arthur. Flora of the Pacific Northwest. Seattle: University of Washington Press; 1973. 730 p.

Hooven, Edward F. Pocket gopher damage on ponderosa pine plantations in southwestern Oregon. Journal of Wildlife Management. 35(2): 346-353; 1971.

Hooven, Edward F.; Black, Hugh C. Effects of some clearcutting practices on small-mammal populations in western Oregon. Northwest Science. 50(4): 189-208; 1976.

Megahan, Walter F. Hydrologic effects of clearcutting and wildfire on steep granitic slopes in Idaho. Water Resources Research. 19(3): 811-819; 1983.

Merritt, Joseph F. *Clethrionomys gapperi.* Shippensburg PA: American Society of Mammalogists, Mammalian Species No. 146; 1981. 9 p.

Overton, W. Scott; Davis, David E. Estimating the numbers of animals in wildlife populations. In: Giles, Robert H., Jr., ed. Wildlife management techniques. 3 ed. Washington, DC: The Wildlife Society; 1969: 403-455.

Petticrew, B. G.; Sadleir, R. M. F. S. The ecology of th deer mouse *Peromyscus maniculatus* in a coastal coniferous forest. I. Population dynamics. Canadian Jour of Zoology. 52(1): 107-118; 1974.

Radvanyi, Andrew. Seed losses to small mammals and birds. In: Direct seeding symposium; 1973 September 11-13; Ottawa, Canada. Publication 1339. Ottawa, Canada: Department of the Environment, Canadian Forestry Service; 1973: 67-75.

Ramirez, Pedro, Jr.; Hornocker, Maurice. Small mamm populations in different-aged clearcuts in northwester Montana. Journal of Mammalogy. 62(2): 400-403; 198

Rickard, W. H. The distribution of small mammals in r tion to the climax vegetation mosaic in eastern Wash ton and northern Idaho. Ecology. 41(1): 99-106; 1960.

Scrivner, Jerry H.; Smith, H. Duane. Relative abundan of small mammals in four successional stages of spru fir forest in Idaho. Northwest Science. 58(3): 171-176 1984.

Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. Forest habitat types of central Idaho General Technical Report INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 198 138 p.

Stickel, Lucille F. A comparison of certain methods of measuring ranges of small mammals. Journal of Mam malogy. 35(1): 1-15; 1954.

Sullivan, Thomas P. Demography of populations of dee mice in coastal forest and clear-cut (logged) habitats. Canadian Journal of Zoology. 57(8): 1636-1648; 1979.

Tevis, Lloyd, Jr. Responses of small mammal populatio to logging of Douglas-fir. Journal of Mammalogy. 37(189-196; 1956.

Ure, Douglas C.; Maser, Chris. Mycophagy of red-back voles in Oregon and Washington. Canadian Journal o Zoology. 60(12): 3307-3315; 1982.

Van Horne, Beatrice. Demography of *Peromyscus man latus* populations in seral stages of coastal coniferous forest in southeast Alaska. Canadian Journal of Zool 59(6): 1045-1061; 1981.

Van Horne, Beatrice. Niches of adult and juvenile deer mice (*Peromyscus maniculatus*) in seral stages of con iferous forest. Ecology. 63(4): 992-1003; 1982.

U.S. GOVERNMENT PRINTING OFFICE: 1986—773-039/41,025 REGION NO. 8

ted States
partment of
riculture

est Service

ermountain
search Station

search Note
-363

vember 1986

Pinyon-Juniper Volume Equations for Arizona Hualapai and Havasupai Indian Reservations[1]

David C. Chojnacky
Janet S. Ott[2]

BSTRACT

'olume prediction equations were developed for pinyon d juniper trees on the Hualapai and Havasupai Indian servations in Arizona. Application of the equations re- ires measurements of total height and tree diameter near root collar. Results are presented in equation and ular formats. Volume equation construction and equa- n reliability are discussed.

YWORDS: *Pinus edulis, Juniperus osteosperma,*
volume table

'TRODUCTION

The Hualapai and Havasupai Indians are interested in nagement of their northern Arizona pinyon-juniper (P-J) ds for firewood production. The tribes depend upon P-J personal uses and for revenue from commercial sales. meet the need for current P-J management informa- n, an inventory of the Hualapai and Havasupai Indian servations was conducted in 1984 and 1985 (USDA 34). Determination of total P-J volume was an impor- it objective of the inventory. Because direct volume asurement is time consuming and costly, data were lected in the inventory on a subsample of trees for later ume equation development. This paper reports the ation construction from these data.

FIELD MEASUREMENTS

Field crews selected one to six trees for volume estimation on each of the 135 plots (fig. 1). The fixed-area plots encompassed a fifth acre when crown cover of the surrounding stand was less than 30 percent, and encompassed a tenth acre when crown cover was more than 30 percent. Within each plot one pinyon and one juniper were randomly selected from each of three diameter classes, 3.0 to 9.9, 10 to 18, and >18 inches diameter at root collar (DRC). Volume estimation was done using visual segmentation, a method of counting the numbers of wood segments within a tree (Born and Chojnacky 1985). Wood segments were determined by dividing tree stems and branches into 1-foot to 6-foot length sections using 2-inch diameter classes. Cubic foot volume was computed for each segment using Huber's log formula (Husch and others 1982, p. 101). For each tree, segments that included wood and bark of all live and dead stems and branches larger than 1.5 inches in diameter were summed into a gross cubic foot volume.

Other tree variables measured for volume equation development were total height, DRC, and number of basal stems. For trees forking at the root collar, an equivalent diameter (EDRC) was calculated for use in place of DRC:

$$\text{EDRC} = \sqrt{\sum_{i=1}^{n} D_i^2} \qquad (1)$$

where

D_i = basal diameter of each stem

n = number of basal stems 1.5 inches or larger.

Species sampled were *Juniperus monosperma* (Engelm.) Sarg., *J. osteosperma* (Torr.) Little, *Pinus edulis* Engelm., and *P. edulis* var. *fallax* Little. In the analysis, the data were grouped by genus because only five of 299 juniper were *J. monosperma* and only 21 of 181 pinyon were *P. edulis* var. *fallax*. Table 1 includes a summary of the raw data.

---

his study was a cooperative effort between the Bureau of Indian Affairs, mountain Research Station, and the Hualapai Tribal Council Forestry artment who collected the field data.

lesearch Forester and Forestry Technician at Intermountain Research ion's Forestry Sciences Laboratory, Ogden, UT.

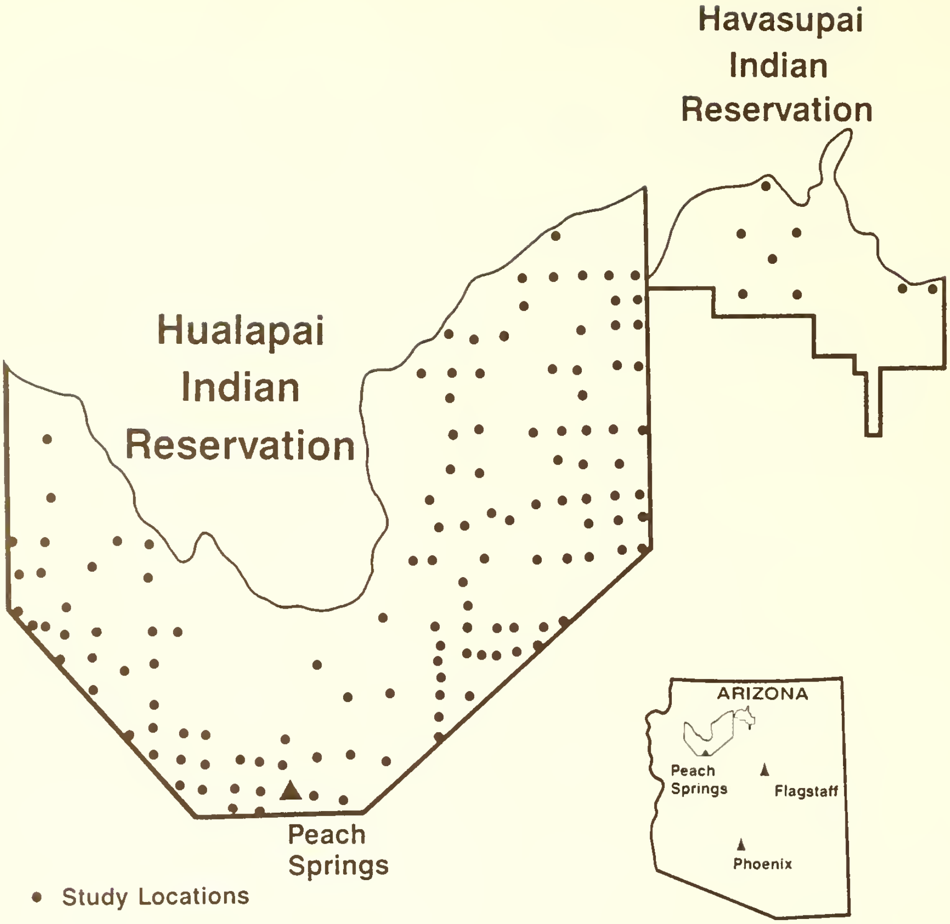


Figure 1—Map of 135 study locations.

Table 1—Summary of Hualapai and Havasupai P-J volume data

Genus	Basal stems	Number of trees	Mean volume	Mean DRC/EDRC	Mean height
			Ft³	*Inches*	*Feet*
Juniper	Multiple	84	10.9	15.1	14.5
	Single	215	8.4	11.3	14.0
	Multiple/single combined	299	9.1	12.4	14.1
Pinyon	Multiple	6	9.1	12.6	16.0
	Single	175	6.0	9.0	17.2
	Multiple/single combined	181	6.1	9.2	17.2

MODELING

A single volume prediction model was sought to estimate volume of all tree sizes represented in the data. Past research has shown DRC, total height, and numbers of basal stems (STEMS) to be important P-J volume prediction variables (Howell 1940; Reveal 1944; Clendenen 1979; Chojnacky 1985).

A simple linear model using a combination variable, DRC squared times height (DRSQH), proved best among initial choices:

$$V = \beta_0 + \beta_1 X$$

(

where

V = gross cubic foot volume of wood and bark from al stems and branches larger than 1.5 inches in diameter

X = DRSQH divided by 1,000

β_i = parameters estimated from data.

The STEMS variable was not used because it added little to the model. Perhaps this was because the data included too few multiple-stem trees (see table 1) or becaus EDRC is a good enough approximation to DRC that no additional variable is needed to distinguish multiple-stem from single-stem trees.

To achieve good volume prediction throughout the rang of tree sizes, the simple linear model (eq. 2) was modified to a two-part model:

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \leqslant X_0 \\ \beta_3 + \beta_1 X + \beta_4 / X & \text{for } X > X_0 \end{cases}$$

(

where

V, X, β_i = same as for eq. 2

X_0 = 5

he two-part volume model was conditioned to be both
ooth and continuous at the point where the two equa-
ns meet. This was done by imposing two restrictions on
model:

$$\beta_3 = \beta_0 + 3\beta_2 X_0^2 \qquad (4)$$

$$\beta_4 = -2\beta_2 X_0^3 \qquad (5)$$

e restrictions were obtained by equating the two parts
equation 3 for $X = X_0$ and by equating the first deriva-
n of the two parts of equation 3 at the point $X = X_0$.
he "joining point" (X_0 =5) was chosen to roughly
arate the large trees from the rest. For juniper, the
ning point corresponded to trees with DRC of about
inches. For pinyon, it corresponded to a tree DRC of
ut 15 inches. Parameters for the two-part model (eq. 3)
re determined using weighted regression with DRSQH
the −1.5 power as the weight (Schreuder and Anderson
34). Final parameter estimates and tabulated volume
dictions are given in tables 2 and 3.

ELIABILITY DISCUSSION

esults of regression goodness-of-fit analyses are sum-
rized in table 4. The coefficient of determination (R^2)
l coefficient of variation (*CV*) were computed without
influence of regression weights to avoid possible misinterpretation. Had weights been used, these regression statistics would have appeared much better because in this case the weights minimized the impact of the larger, highly variable trees. On the other hand the confidence intervals (*CI*) were computed using the regression weights (SAS 1985) because no unweighted alternative seemed reasonable.

The R^2 indicated sufficient fit of the volume model to the data for trees less than 15 to 18 inches DRC, but it indicated a poor fit for larger trees. The coefficient of variation (*CV*) showed large variation for the regression standard error to mean volume ratio. The consequence of this large variation on future predictions was assessed by constructing 95 percent confidence intervals (*CI*) to predict sample means.

Results for four sample sizes used to predict the median size tree in two DRC classes are illustrated in table 4. For example, if 10 juniper trees about 10 inches in DRC were measured for volume prediction, the expected true volume would lie in an interval plus or minus 28 percent of 3.1 ft^3 (2.2 to 4.0 ft^3). If 30 junipers of 10 inches were sampled, the expected true volume would lie in a smaller interval of plus or minus 17 percent of 3.1 ft^3 (2.6 to 3.6 ft^3). A sample size of 50 would further reduce the confidence intervals, but the amount of confidence interval reduction in relation to sample size diminishes considerably beyond sample size 30.

Table 2—Juniper gross outside bark volume[1] of stem and branch wood larger than 1.5 inches in diameter

DRC	Height (feet)																Number of trees
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	
Inches	*Cubic feet*																
4	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.7								41
6	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.7			31
8	0.6	0.9	1.2	1.6	1.9	2.2	2.5	2.9	3.2	3.6	3.9	4.2	4.6	4.9	5.3	5.6	29
10	1.0	1.5	2.0	2.5	3.0	3.5	4.1	4.6	5.1	5.7	6.2	6.8	7.3	7.9	8.5	9.0	38
12		2.1	2.9	3.6	4.4	5.2	6.0	6.8	7.6	8.4	9.2	10.0	10.9	11.7	12.6	13.5	39
14		2.9	4.0	5.0	6.1	7.2	8.3	9.4	10.5	11.7	12.9	14.1	15.2	16.4	17.5	18.6	30
16			5.3	6.7	8.1	9.6	11.1	12.6	14.1	15.7	17.2	18.6	20.0	21.4	22.8	24.2	17
18			6.8	8.6	10.5	12.4	14.3	16.3	18.1	19.9	21.7	23.4	25.2	26.9	28.6	30.3	13
20			8.5	10.8	13.2	15.6	17.9	20.1	22.3	24.4	26.6	28.7	30.7	32.8	34.9	36.9	24
22				13.3	16.2	18.9	21.6	24.2	26.8	29.3	31.8	34.3	36.8	39.3	41.7	44.2	15
24				16.0	19.3	22.5	25.5	28.6	31.6	34.5	37.5	40.4	43.4	46.3	49.2	52.1	10
26					22.6	26.2	29.7	33.2	36.7	40.2	43.6	47.0	50.4	53.8	57.2	60.6	8
28					26.1	30.2	34.2	38.2	42.2	46.2	50.1	54.1	58.0	62.0	65.9	69.8	1
30					29.7	34.4	39.0	43.5	48.1	52.6	57.1	61.7	66.2	70.7	75.2	79.7	3
32						38.8	44.0	49.2	54.3	59.5	64.6	69.7	74.8	80.0	85.1	90.2	0
34						43.5	49.3	55.2	61.0	66.7	72.5	78.3	84.1	89.8	95.6	101.4	0
Number of trees	3	12	30	28	45	45	42	38	23	15	10	4	2	2	0	0	299

[1] Volume = $-0.05 + 2.48 \cdot X + 0.057 \cdot X^2$ for $X \leqslant 5$
$4.24 + 2.48 \cdot X - 14.29/X$ for $X > 5$
where: X = DRC·DRC·Height/1,000.

Table 3—Pinyon gross outside bark volume[1] of stem and branch wood larger than 1.5 inches in diameter

DRC	Height (feet)																		Numbe of tree
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	
Inches	*Cubic feet*																		
4	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.7										34
6	0.3	0.5	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8					32
8	0.6	0.9	1.2	1.6	1.9	2.3	2.6	3.0	3.3	3.7	4.0	4.4	4.7	5.1	5.5	5.9	6.2	6.6	27
10	0.9	1.5	2.0	2.5	3.1	3.6	4.2	4.8	5.3	5.9	6.5	7.1	7.7	8.3	9.0	9.6	10.2	10.9	32
12		2.2	3.0	3.7	4.6	5.4	6.2	7.1	8.0	8.9	9.8	10.7	11.6	12.6	13.6	14.6	15.6	16.5	24
14		3.0	4.1	5.2	6.4	7.6	8.8	10.0	11.3	12.6	13.9	15.3	16.6	17.9	19.1	20.3	21.5	22.7	16
16			5.5	7.0	8.6	10.2	11.9	13.6	15.4	17.1	18.7	20.3	21.9	23.4	24.9	26.3	27.8	29.2	5
18			7.1	9.1	11.2	13.3	15.6	17.7	19.8	21.7	23.7	25.5	27.4	29.2	30.9	32.7	34.5	36.2	5
20			9.0	11.5	14.2	17.0	19.5	22.0	24.3	26.6	28.8	31.0	33.2	35.4	37.5	39.6	41.7	43.8	4
22				14.4	17.6	20.7	23.6	26.3	29.1	31.7	34.3	36.9	39.5	42.0	44.6	47.1	49.6	52.1	1
24				17.5	21.1	24.5	27.8	30.9	34.1	37.2	40.2	43.2	46.3	49.2	52.2	55.2	58.2	61.1	1
26					24.6	28.5	32.2	35.8	39.4	43.0	46.5	50.0	53.5	57.0	60.5	63.9	67.4	70.8	0
28					28.3	32.6	36.8	41.0	45.1	49.2	53.2	57.3	61.3	65.3	69.3	73.3	77.3	81.2	0
Number of trees	0	6	9	20	23	11	21	13	24	19	12	4	7	6	1	2	1	2	181

[1] $\text{Volume} = -0.07 + 2.51 \cdot X + 0.098 \cdot X^2$ for $X \leqslant 5$

$7.29 + 2.51 \cdot X - 24.53/X$ for $X > 5$

where: $X = \text{DRC} \cdot \text{DRC} \cdot \text{Height}/1{,}000$.

Table 4—Regression statistics from Hualapai and Havasupai P-J volume modeling

Genus	DRC class	Number of trees	R^2	*CV*	Median statistics[1]					
					Predicted volume	Median DRC	95% mean[2] *CI*			
							n = 10	n = 30	n = 50	n = 100
	Inches			*Pct.*	*Ft*^{3}	*Inches*	*Percent*			
Juniper	<18	230	0.77	51	3.1	10	28	17	14	11
	>18	69	.59	35	22.7	21	16	11	9	8
Pinyon	<15	165	.84	42	3.2	9	23	15	12	10
	>15	16	.42	27	26.8	18	14	10	9	9

[1] Statistics based on the median of the DRC class.

[2] Confidence intervals (*CI*) for mean predicted volume for several sample sizes for the median level of DRSQH (roughly median DRC) in each DRC class. *CI*'s are expressed as a percentage of predicted volume for each DRC class.

REFERENCES

Born, J. D.; Chojnacky, D. C. Woodland tree volume estimation: a visual segmentation technique. Research Paper INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1985. 16 p.

Chojnacky, D. C. Pinyon-juniper volume equations for the central Rocky Mountain States. Research Paper INT-339. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 27 p.

Clendenen, G. W. Gross cubic-volume equations and tables, outside bark for pinyon and juniper trees in northern New Mexico. Research Paper INT-228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 21 p.

Howell, J. Piñon and juniper: a preliminary study of volume, growth, and yield. Regional Bulletin 71. Albuquerque, NM: U.S. Department of Agriculture, Soil Conservation Service; 1940. 90 p.

Husch, B.; Miller, C. I.; Beers, T. W. Forest mensuration. 3d ed. New York: Ronald Press Company; 1982. 402 p.

Reveal, J. F. Singleleaf pinyon and Utah juniper woodlands in western Nevada. Journal of Forestry. 42: 276-278; 1944.

SAS Institute, Inc. SAS user's guide: statistics, version 5 edition. Cary, NC: SAS Institute, Inc.; 1985. 956 p.

Schreuder, H. T.; Anderson, J. A. Variance estimates for volume when D^2H is the covariate in regression. Canadian Journal of Forest Research. 14(6): 818-821; 1984.

U.S. Department of Agriculture, Forest Service. Hualapai and Havasupai Indian Reservations forest survey field procedures, 1984. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Forest Survey; 1984. 2 parts.

ted States
partment of
iculture

est Service

ermountain
search Station

search Note
-364

cember 1986

Edaphic Relationships in Climax Singleleaf Pinyon Stands of Western Nevada

Harry B. Summerfield
Ray L. Miles
Stephen G. Leonard
Richard L. Everett[1]

BSTRACT

'e examined soil series and soil properties that are ociated with climax singleleaf pinyon (Pinus mono-lla) *stands in western Nevada. This information is ful in inventorying woodland and range resources and land use planning. We used the Soil Resource Informa-l System Program to evaluate and test soil properties ociated with singleleaf pinyon. Soils supporting single-f pinyon stands commonly had mollic epipedons, argillic izons, shallow depth to bedrock, mesic temperature imes, and low available water capacities. The 11 soil ies associated with climax stands of singleleaf pinyon nds occur on 7 percent of the land surface (approximate-l88,000 acres) in western Nevada. These soils have low ential for forage production and are best suited for pro-ing wood products.*

YWORDS: soils, plant-soil relationships, woodlands

TRODUCTION

ur objectives were to determine the kinds of soils on ich climax stands of singleleaf pinyon (*Pinus mono-lla*) occur in western Nevada and to make interpreta-ıs about important soil properties that are associated h pinyon stands. Data from four published soil surveys western Nevada were used as the data base. We ob-ned information on the relationship between soil and getation from the Soil Resource Information System[2] RIS). This report includes descriptions of soil series and properties associated with singleleaf pinyon and pro-es management implications.

METHODS

Soil and vegetation information from the SRIS program on the Fort Collins Computer System 2000 identified soils and soil properties associated with climax stands of singleleaf pinyon. Order III soil surveys from four survey areas (Carson City, Douglas, Lyon, and Washoe County-south part—2,780,672 acres) in western Nevada were used as the data base.

Information about mollic epipedons, argillic horizons, soil temperatures, soil depth to bedrock, rock fragment content, pH, clay content, parent material, and available water capacity was evaluated for each soil series associated with climax singleleaf pinyon stands. We analyzed understory components of the vegetation for constancy (percentage occurrence) among the soil series.

RESULTS AND DISCUSSION

We found 11 soil series regularly associated with climax singleleaf pinyon stands in western Nevada. Taxonomic classifications for these soil series are presented in table 1. These soils are on ridges, side-slopes, and pediments of numerous mountain ranges and occupy approximately 188,300 acres or 7 percent of the land surface in the soil surveys. Soil series associated with singleleaf pinyon belong in the Mollisol, Aridisol, and Entisol orders (USDA Soil Conservation Service 1975). Texture varies from loamy to clayey and soils are commonly skeletal (greater than 35 percent rock fragments).

Soil properties associated with these soil series are given in table 2. The soils have a mollic or argillic horizon and usually both. Soil temperature regimes are mesic (mean

---

oil scientist, Toiyabe National Forest; soil scientist and range conserva-st, National Soil-Range Team (U.S. Department of Agriculture, Soil servation Service and U.S. Department of the Interior, Bureau of Land agement); and project leader, Intermountain Research Station, Reno,

[2] SRIS, Soil Resource Information System, was cooperatively developed by Colorado State University, Soil Conservation Service, Agricultural Research Service, and Laboratory Information Science in Agriculture on the USDA Fort Collins Computer System 2000.

Table 1—Soil series and families associated with climax stands of singleleaf pinyon in western Nevada

Soil series	Soil family[1]
Berit	Loamy-skeletal, mixed, mesic, shallow, Xerollic Haplargids
Cagle	Fine, montmorillonitic, mesic, Aridic Argixerolls
Duco	Clayey, montmorillonitic, mesic, Lithic Argixerolls
Hyloc	Clayey, montmorillonitic, mesic, shallow, Aridic Argixerolls
Itca	Clayey-skeletal, montmorillonitic, frigid, Lithic Argixerolls
Koontz	Loamy-skeletal, mixed, mesic, shallow, Aridic Argixerolls
Kram	Loamy-skeletal, carbonatic, mesic, Lithic Xeric Torriorthents
Minneha	Loamy-skeletal, mixed, mesic, shallow, Aridic Haploxerolls
Nall	Loamy, mixed, mesic, shallow, Aridic Haploxerolls
Searles	Loamy-skeletal, mixed, mesic, Aridic Argixerolls
Wile	Clayey, montmorillonitic, mesic, shallow, Aridic Argixerolls

[1] Soil descriptions follow Soil Conservation Service (1975).

Table 2—Characteristics of soils supporting climax stands of singleleaf pinyon in western Nevada

Soil series	Mollic[1] epipedon	Argillic horizon	Temperature regimes		Depth to bedrock		Range in available water capacity	
			Mesic	Frigid	20	>20	Low	High
					Inches			
Beri	[2]—	X	X		X		[3]0.47	0.64
Cagle	X	X	X			X	3.02	3.47
Duco	X	X	X		X		1.46	1.77
Hyloc	X	X	X		X		1.76	2.36
Itca	X	X	—	X	X		1.65	1.99
Koontz	X	X	X		X		1.30	1.58
Kram	—	—	X		X		1.00	1.21
Minneha	X	—	X		X		1.08	1.37
Nall	X	—	X		X		.48	.64
Searles	X	X	X			X	3.68	4.44
Wile	X	X	X		X		1.89	2.34

[1] Definitions of epipedons, horizons, temperature regimes, and available water capacity are too lengthy for inclusion in the table or text. The reader is referred to the Soil Conservation Service (1975).

[2] X denotes the presence and - the absence of soil characteristic in the soil series.

[3] Total water capacity for the entire profile.

annual soil temperatures are 46 to 59 °F with one exception). Depth to bedrock is less than 20 inches for all soil series except Cagle and Searles series, which have deeper soils. There is no consistency in pH (6.3 to 7.8) and clay content (4 to 50 percent) among soil series. Parent materials of the 11 soil series were varied (four granitic, six volcanic, and one limestone). Rock fragment content was less than 35 percent in five soil series and greater than 35 percent (skeletal soils) in six others.

Forage production of the understory in closed singleleaf pinyon stands is generally less than 50 lb/acre, dry weight. Removal of trees can increase production to 600 lb/acre, but production is site specific and dependent upon soil, slope, aspect, precipitation, and plant species present (personal communication, Ken Genz, Toiyabe National Forest). In a case study in central Nevada, forage production increased from 25 to 27 lb/acre on a south slope, 23 to 345 lb/acre on a west slope, and 56 to 197 lb/acre on a north slope following tree removal from closed stands (Everett and Sharrow 1985). Forage production can be much higher (800 to 1,100 lb/acre) on associated soils such as the Nosrac series that occurs in some of the same mapping units with woodland soils (Candland 1981). The Nosrac soil has a mollic epipedon and an argillic horizon but greater depth to bedrock (60 inches) and more available water capacity in the entire profile (6.18 to 7.2 inches).

Understory associated with climax singleleaf pinyon ands was mostly shrubs: Wyoming big sagebrush ɪrtemisia tridentata wyomingensis), low sagebrush ɪrtemisia arbuscula), black sagebrush (*Artemisia nova*), nd antelope bitterbrush (*Purshia tridentata*). Bitterbrush ad the highest constancy (80 percent) among the soil eries.

IANAGEMENT IMPLICATIONS

Soils associated with climax stands of singleleaf pinyon ave low potential to produce significant amounts of rage. Vegetation type conversions such as chaining, urning, clearcutting, or herbicide spray have had little uccess on these soils. Conversion treatments may result a minor release of sagebrush and bitterbrush species to enefit wildlife. We suggest these soils are best used and anaged to provide wood products. Firewood, fenceposts, inenuts, and Christmas trees are valuable resource roducts, and demand for these products has increased ramatically in the last decade.

UMMARY

Climax singleleaf pinyon stands occur on soils of low otential for producing forage. Shallow soil and rock agments limit available water capacity. Remnant nderstory vegetation (mostly shrubs) cannot be expected be very productive following tree removal because of te constraints. Wood production should be the primary se for these soils.

REFERENCES

Archer, W. M. Soil survey of Lyon County Area, Nevada. Washington, DC: U.S. Government Printing Office; 1984. 513 p.

Baumer, O. W. Soil survey of Washoe County, Nevada, south part. Washington, DC: U.S. Government Printing Office; 1983. 608 p.

Candland, D. M. Soil survey of Carson City area, Nevada. Washington, DC: U.S. Government Printing Office; 1979. 169 p.

Candland, D. M. Soil survey of Douglas County Area, Nevada. Washington, DC: U.S. Government Printing Office; 1981. 575 p.

Everett, R. L.; Sharrow, S. H. Response of grass species to tree harvesting in singleleaf pinyon-Utah juniper stands. Research Paper INT-334. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 7 p.

U.S. Department of Agriculture, Soil Conservation Service. National Soil Handbook 602. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1983. 138 p.

U.S. Department of Agriculture, Soil Conservation Service. Soil taxonomy. Agriculture Handbook 436. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, Soil Survey Staff; 1975. 754 p.

U.S. Department of Agriculture, Forest Service. Range Analysis Handbook 2209.21. Washington, DC: U.S. Department of Agriculture, Forest Service; 1982.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

ited States
partment of
riculture

rest Service

ermountain
search Station

search Note
T-365

nuary 1987

HIDE2: Evaluation of Elk Hiding Cover Using a Personal Computer

L. Jack Lyon[1]

BSTRACT

n IBM[2] compatible program for personal computers described. Input requirements are forest stand ructural data; tree densities by diameter class. tput is an estimate of elk hiding cover values. nopy diameter of shrubs and of trees with lower vel foliage can be included in the evaluation. The ogram assumes random distribution of plants and oduces a visual image representing 1 acre.

EYWORDS: PC program, wildlife management, elk habitat

Coordination of elk habitat management and timber anagement on the National Forests requires mparison of existing elk habitat to habitat quality andards described in forest plans. These standards ll for compilation of hiding cover and thermal cover lues of forest stands. Identification of thermal ver, defined by crown canopy closure, poses no surmountable problems because crown closure can e estimated from aerial photographs. Identification hiding cover, however, can be extremely difficult ecause determination from aerial photographs is not ossible, and there is rarely adequate time to obtain eld samples.

This Research Note describes a program for personal mputers that utilizes available timber stand formation, produces hiding cover estimates with peed and precision, and runs on any IBM compatible C (Lyon 1985). A mainframe version in FORTRAN also available.

HIDE2: HOW IT WORKS

The currently accepted and widely used definition assumes that Hiding Cover is provided when vegetation hides 90 percent of an elk at 200 feet (Thomas and others 1979). Thus, in order to satisfy the definition, vegetation must visually obstruct the line of sight between an observer and an elk at a distance of 200 feet--and must do so in a block of sufficient width to hide an elk.

The PC program HIDE2 assumes an observer in a forest stand evaluating all points on an arc 200 feet away in increments of 1 inch. The percentage of such points made invisible by either stems or vegetation canopy is considered visual blockage. Visual blockage along the arc is evaluated in units 65 inches wide. By definition, only those units that provide 90 percent or greater visual blockage are classified as hiding cover.

The unique specialty of the PC program is that it displays the forest stand being evaluated on the screen. Input of already available stand inventory information, diameter (d.b.h.), and density (plants per acre) is requested sequentially. As answers are supplied, the following assumptions are made within the program:

Trees–all diameters up to 30 inches are considered to be tree stems. Visual blockage is created only by the stem.

Small Trees–diameters under 6 inches can be entered either as stems or as open-grown trees. Visual blockage by foliage is assumed when the diameter entry is followed by "+". The applicable foliage crown width is assumed to be 1 foot for each inch of stem diameter.

Shrubs–diameters from 30 to 90 inches are considered to be shrubs and are evaluated for visual blockage created by foliage.

As each class of vegetation is entered, random locations are generated for individual plants and the

---

[1] Wildlife research biologist stationed at Intermountain Station's Forestry iences Laboratory, Missoula, MT.

[2] The use of trade or firm names in this publication is for reader formation and does not imply endorsement by the U.S. Department of griculture of any product or service.

stand is plotted on the screen at about 1:500 scale for an area representing approximately 1 acre. Symbols for trees and shrubs of various types are appropriately scaled. Intermediate output consists of accumulated totals for Plant Density, Visual Blockage, and Hiding Cover.

Entry of a diameter greater than 90 terminates the program and produces summary output. In addition to Hiding Cover, output includes a 10-class frequency distribution of visual obstruction percentages.

HIDE2: DISTRIBUTION

The program HIDE2 is available from the author at no cost on receipt of a floppy disk. The program was written on an ATT PC6300, using MS-DOS 2.11 and GWBASIC 2.0. It has been tested for compatibility on an IBM PC, MS-DOS 2.10, and BASICA. It was designed for use with a color monitor, but it will run without modification on a monochrome monitor.

REFERENCES

Lyon, L. Jack. 1985. HIDE--modeling hiding cover for wildlife. PC program. In: Session III - Demonstrations of micro-computer applications: national workshop on micro-computer applications in fish and wildlife programs; 1985 October 9-11; Fort Collins, CO. Fort Collins, CO: Colorado State University. [Unnumbered].

Lyon, L. Jack; Marcum, C. Les. 1986. Field test of a PC program to evaluate hiding cover for elk. In: Proceedings, 1986 western states and provinces elk workshop; 1986 March 17-19; Coos Bay, OR. Portland, OR: Oregon Department of Fish and Wildlife: 271-274.

Thomas, Jack Ward; Black, Hugh, Jr.; Scherzinger, Richard J.; Pedersen, Richard J. 1979. Deer and elk. In: Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture, Forest Service: 104-127.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-366

Design and Construction of an Electric Arc Generator for Fuel Ignition Studies

Don J. Latham[1]

ABSTRACT

Describes design and construction of a system for creating a vertical, unbounded arc discharge in air. The arc is initiated by an exploding tungsten wire and is turned on and off by a silicon-controlled rectifier switching system. As a safety precaution, all circuits are computer controlled through fiber optic and pneumatic connecting links. The SCR switch and decommutator switch are fully protected against excessive current and voltage rate-of-rise. Typical waveforms for short-circuit and arc switching are presented.

KEYWORDS: arc generator, arc discharge, vertical arc

Lightning flashes to ground consist usually of a discharge with a peak current flow on the order of 30,000 amperes. The discharge duration is about 400 microseconds. Occasionally, a weaker spark discharge of 10,000 amperes or so will be followed by a much smaller current flow. This 20 to 500 ampere current lasts up to 500 ms, and is called a continuing current by lightning researchers (see Uman 1984 for summary). The continuing current is responsible for 95 percent of all lightning-caused wildfires (Fuquay and others 1972).

Because this fire-starting mechanism is of such importance, and because means are now at hand to locate the ground termini of lightning discharges (for example, the Bureau of Land Management's IAMS system), we have been working on a means of predicting the probabilities of fire starts by lightning discharges (Fuquay and others 1979). The probabilities, together with accurate lightning locations in a predictive system, will enable cost savings in fire-spotting patrols and aid in control/confine/contain decisions (Latham 1979).

To predict the probability of fire occurrence, we need to determine only the probability of ignition of a fuel complex; the propagation probability of the fire is known (Wilson 1985). Ignition probability depends on the physical parameters of the fuel, such as fuel type, bulk density, and the like; on fuel state, in particular moisture content; and on the reaction of the fuel to the passage of an electrical arc discharge.

We began our study of this problem by using modeling techniques to obtain some sense of the characteristics of the continuing current arc channel (Latham 1980, 1986). Combining these with known characteristics of the continuing current, we formed a set of criteria for an electric arc to simulate the continuing current in the laboratory. Using these criteria, we designed and constructed equipment to generate the arc and measure its current flow.

DESIGN CRITERIA

From measurements of naturally occurring continuing currents and from our modeling efforts, we obtained a set of desired characteristics for the arc discharge:

- current in the arc from 20 to 500 amperes dc
- arc duration 20 to 500 ms (0.02 to 0.5 sec)
- fast start and stop of current flow
- core temperature 6,000-8,000 K
- length greater than 10 cm
- diameter 1-6 cm

In addition to these modeling criteria, safety of personnel and building was of paramount importance in switching and power supply design.

We needed an estimate of the voltage requirements of the power supply. We could expect an electrode drop of 25 to 30 volts across the anode and a like drop at the cathode (Cobine 1958). Model (Latham 1980, 1986) and experiment (King 1961) showed that a 10-cm-long arc would have a voltage drop of about 100 volts, nearly independent of current flow, over our range of interest. Although we wanted a constant current source, we could not find a dc control element that would serve. The current

---

[1] Research meteorologist/physicist located at Intermountain Research Station's Fire Sciences Laboratory, Missoula, MT.

flow could, however, be set by a series resistor. The series resistor would also act as a current-limiting element to prevent total "meltdown" in the event of circuit failure. The source voltage necessary for a 10-cm arc from a simple equivalent circuit (the power supply in series with the limiting resistor and the arc) was calculated as:

$$Vs = 700 * R_{sm} + 0 \quad \text{(arc shorted)}$$

$$Vs = 500 * R_{sm} + 150 \text{ (10-cm arc)}$$

where Vs is the source voltage, R_{sm} is the minimum source series resistance, the maximum current flow is 700 amperes, and the arc voltage drop is 150 volts at a current of 500 amperes. The maximum current flow was chosen only slightly higher than the cranking current of the (anticipated) battery supply. Under these conditions, the source voltage is 525 volts, the minimum series resistance 0.75 ohms, and the maximum series resistance (corresponding to 20 amperes of current) is 18.75 ohms.

The source voltage and short-circuit current established the minimum values for the capabilities of the switch. It must control a sustained current of at least 700 amps and have a voltage breakdown of at least 525 volts. We used an engineering safety factor of about 2, requiring 1,000 volts standoff and 1,500-2,000 ampere current capacity for 1 sec as the design values for the switch. At this current, for 1 sec, the series resistor must dissipate 1,500 to 2,000 kw without heating to destruction. Because we expected an interval of several minutes between arcs, "one-shot," or nonrepetitive, ratings of switching devices were used.

SAFETY

A primary consideration in the design and construction of the arc system was personnel and building safety. We needed a high-voltage supply capable of up to 1 kiloampere current capacity at a voltage in excess of 500 volts; therefore, a means of preventing access to and interlocking the supply was mandatory. Because of the high current needs, and the state of the building electrical supply, we could not use transformer-rectifier combinations for the primary supply. After some alternatives had been considered, we decided that forty large automotive storage batteries connected in series would serve. These would be placed in a building separate from the main building, and the separate building kept locked at all times. Although lead-acid batteries only generate hydrogen when being charged rapidly, personnel fears about formation of hydrogen gas were allayed by using the ventilated outbuilding, and by using small, inexpensive automotive battery chargers. To allow this use, and to prevent danger from a permanent series connection, switches were designed for automated series connection of groups of four permanently series-connected batteries. All 10 of these switches were to be closed only just prior to generating the arc. Further safety considerations prompted the choice of a combination of pneumatic and fiber optic devices to do all control functions. No connections of any kind would be made to commercial power lines; additional storage batteries would supply all needed voltages in the switching circuit. An easy-to-use manual switch would interrupt the high-voltage circuit in extremis. This switch would also disable all other circuits in the high-voltage switching circuit.

After much deliberation, we decided that the high-voltage circuit would have no earth ground. If "one hand for the work and one for me" was obeyed, personnel could not inadvertently bridge the power supply. All circuitry for the high-voltage switch would be completely enclosed in cabinets and attention paid to security of all electrical insulation.

Further safety precautions included provision of ample numbers of fire extinguishers of the proper kind, a vent with fan for removing smoke and vapors, first aid kits, appropriate operator training, and great numbers of high voltage signs. Because we planned to use tungsten for the exploding wire, toxicity of tungsten and tungsten oxide was checked and found nil.

ARC GENERATOR CIRCUIT DESCRIPTION

The arc generator as it now exists is best understood by examining the figures (schematic diagrams and photographs) depicting its components. Begin with figure 1, the overall block diagram. Arrows point to control and power connections. The main elements of the generator are: (1) the computer and fiber optics interface, (2) the controller electronics, (3) the high voltage power supply with its series switches, (4) the arc-switching circuit, (5) the electrode assembly (arc carrier), and (6) the current measurement instrumentation.

The PET 4001 computer[2] is a now obsolete microcomputer with 32k bytes of RAM and BASIC in ROM. W chose this computer because it was on hand and because i has an IEEE488 bus driver built in. It has more than sufficient memory to do the job, a dual floppy disk drive storage, and a printer. The computer controls, through its IEEE bus, a binary interface that drives and receives information from the fiber optics interface to the controller (fig. 2). The bus also connects the computer and the storage oscilloscope. The fiber optics interface is an array of drivers and receivers (fig. 3A,B). All system functions are controlled by this computer, including arc duration, system sequencing, operator instructions, and operation of th sampling oscilloscope. An external fiber optic pushbutton is used to fire the arc switch. Figure 2 is a photograph of the computer, fiber optics interface, and sampling oscilloscope assemblies.

The pneumatic supply referenced in figure 1 is relatively simple. Air from the laboratory supply at 70 psi is passed through a dryer, regulator, and buffer tank. The regulator was set at 55 psi. A valve was installed on the fiber optics interface panel to control the air supply to the rest of the apparatus. This valve, as a safety feature, is no automated, so the operator can shut down the pneumatic at any time.

---

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

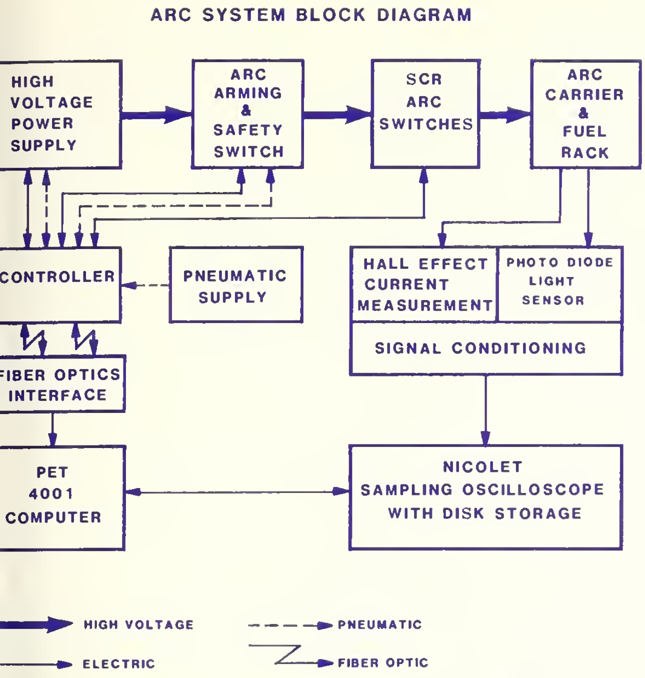


Figure 1—Arc generator system block diagram.

igure 2—The computer and fiber optics nterface (left) and the Hall-effect current neasuring signal conditioner and digital sampling oscilloscope (right).

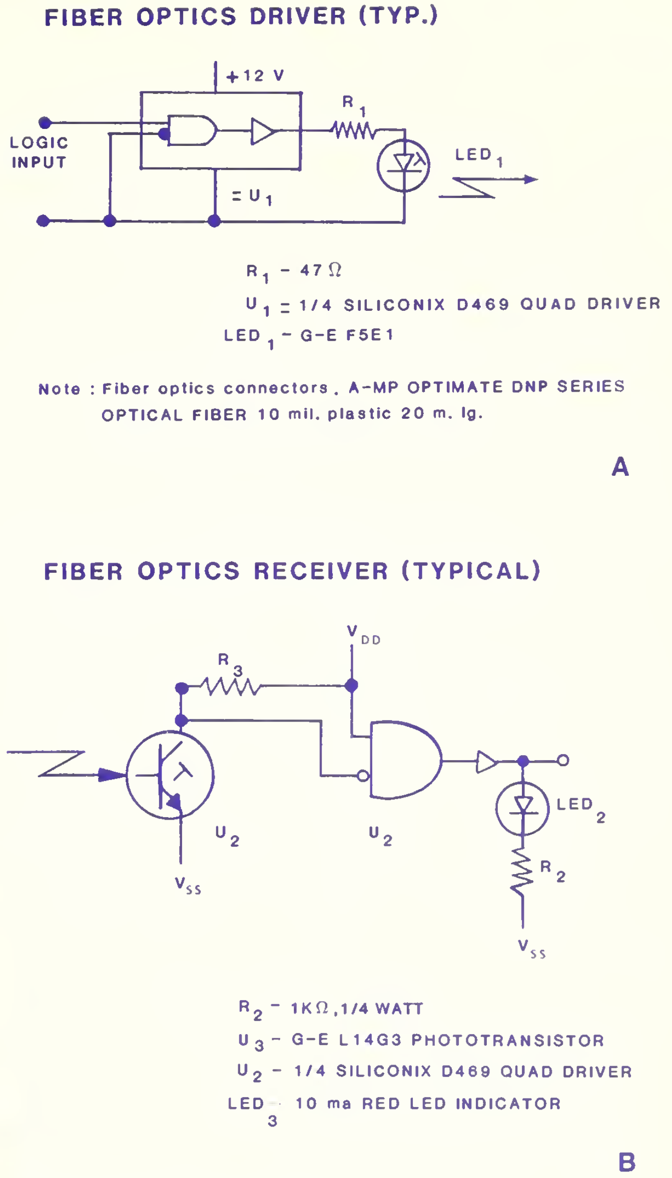


Figure 3—Fiber optics driver (A) and receiver (B) circuit diagrams.

The controller (fig. 4) is connected to the non-high-voltage world through fiber optics and the pneumatic supply line to meet the safety criteria given above. It resides, along with its 12-volt battery power supply, in the arc switch cabinet. The arc arming switch and the high-voltage switch assembly are pneumatically driven, the pneumatics controlled by fiber optics valve driver circuits (fig. 5). Pneumatic cylinders have long mechanical throw with excellent force, allowing for switches with large air gap electrical isolation. The safety bleed valve is part of the manual safety switch (which we will see later) and is opened when that switch is in the open position. If this valve is open, the air supply to the high-voltage circuits is removed, disabling the high-voltage power supply and the arc arming switch.

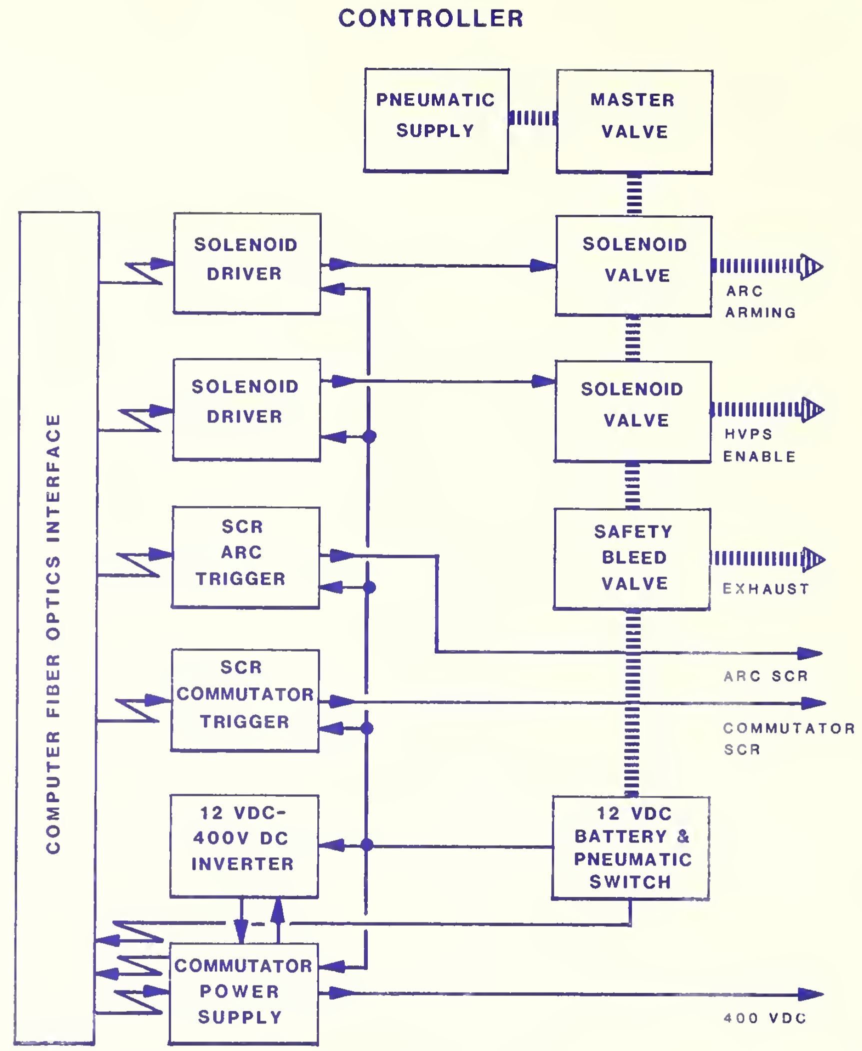


Figure 4—Controller block diagram (ref. fig. 1).

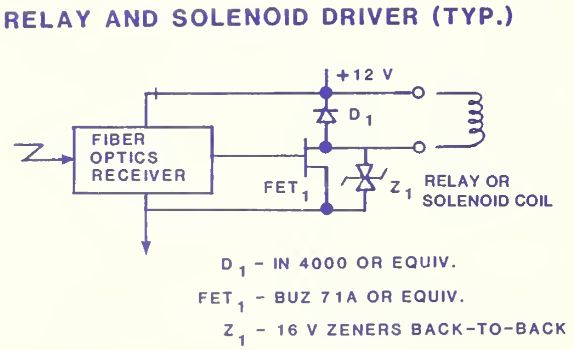
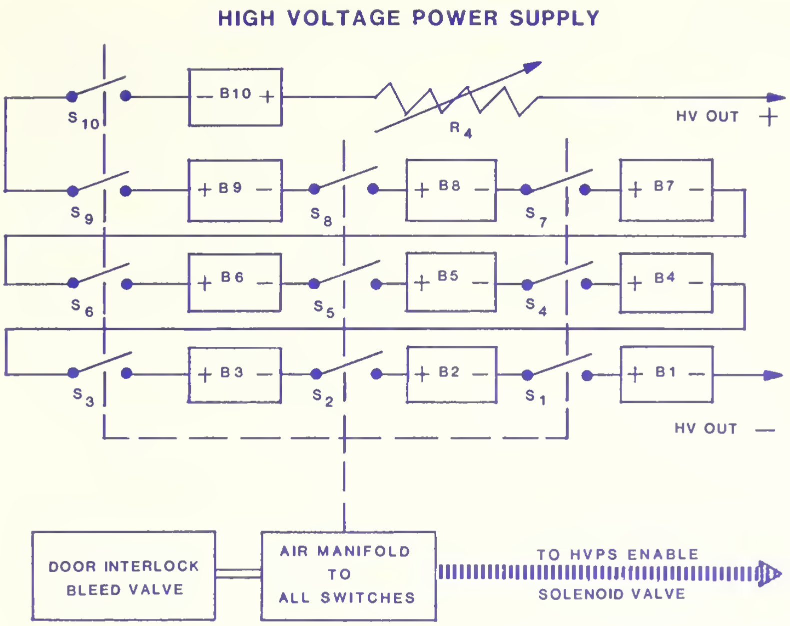


Figure 5—Relay and solenoid driver (ref. fig. 4).

The high-voltage power supply, figure 6, consists of forty 12-volt heavy-duty automotive batteries (B_1-B_{10}), each having a cranking current of 620 amperes. The cranking current is the current source value at zero degrees Fahrenheit. The current source value is higher at the 50 °F minimum temperature of the battery shed. The batteries are permanently connected in series groups of four, and 10 pneumatic switches (S_1-S_{10}), shown in detail in figures 7 and 8, connect the four-battery groups together in series immediately before an arc discharge is t be made. These switches, as can be seen in figures 8 and 9 are built on the lumber used for shelf supports. Figure 8 is a detail photograph of a switch, and figure 9 shows the switches with protective covers in place. The little indicator flag evident in figure 8 is displayed above the safety cover when the switch is closed. A valve is connected to the building door so that if the door is opened when the series switch circuit is energized, the air supply is interrupted, and all switches in the battery building open.

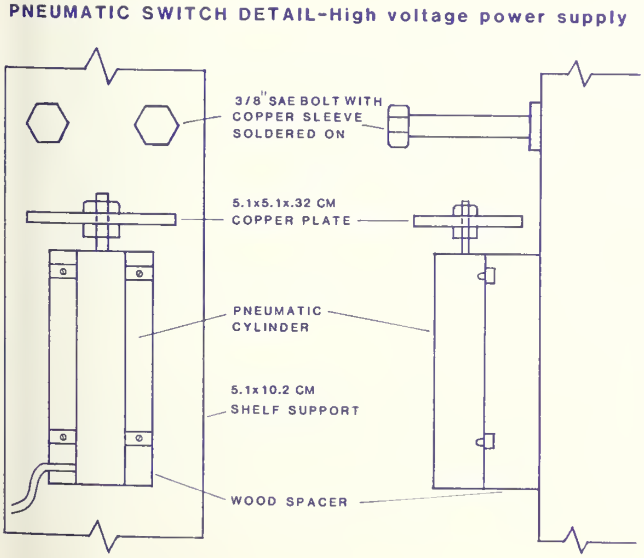


B_1 - B_{10} - CLUSTER OF FOUR 12 V LEAD-ACID BATTERIES, 620 A CRANKING CURRENT, GENERAL BATTERY CORP. 31-620

R_4 - 0-10 Ω RHEOSTAT• 50 EA. 4.8 MM DIA. x 61 CM LG. CARBON WELDING RODS IN SERIES

S_1 - S_{10} - PNEUMATIC HIGH VOLTAGE SWITCH (See detail)

Figure 6—Circuit diagram of the high-voltage power supply (ref. fig. 1).



gure 7—Detail drawing of the high-voltage power pply switch (ref. fig. 6).

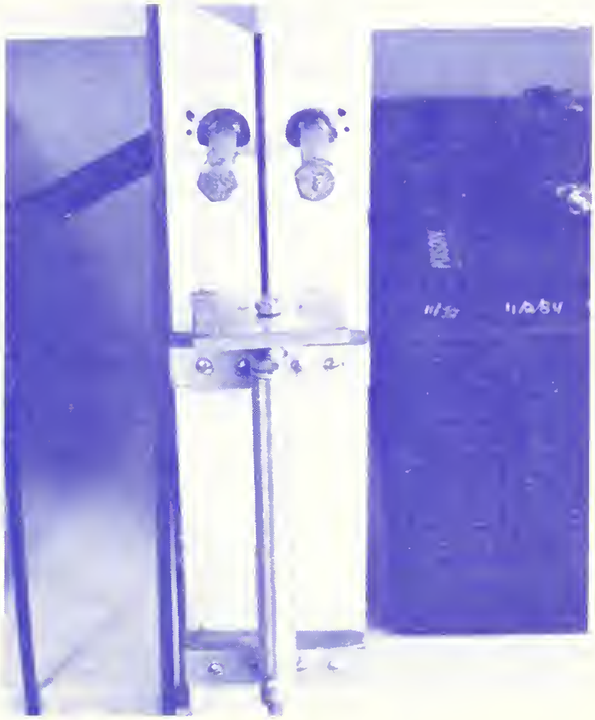


Figure 8—One of 10 high-voltage switches (ref. fig. 7).

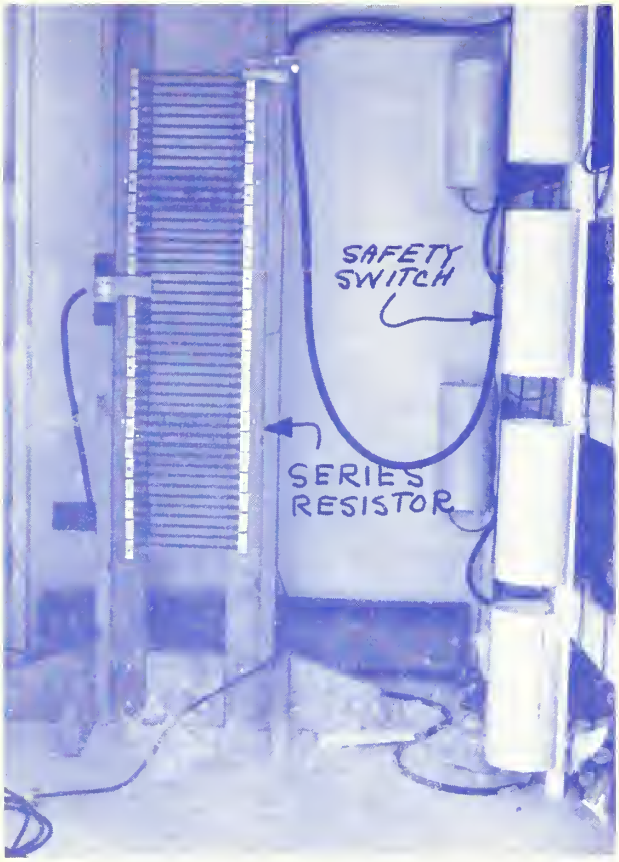
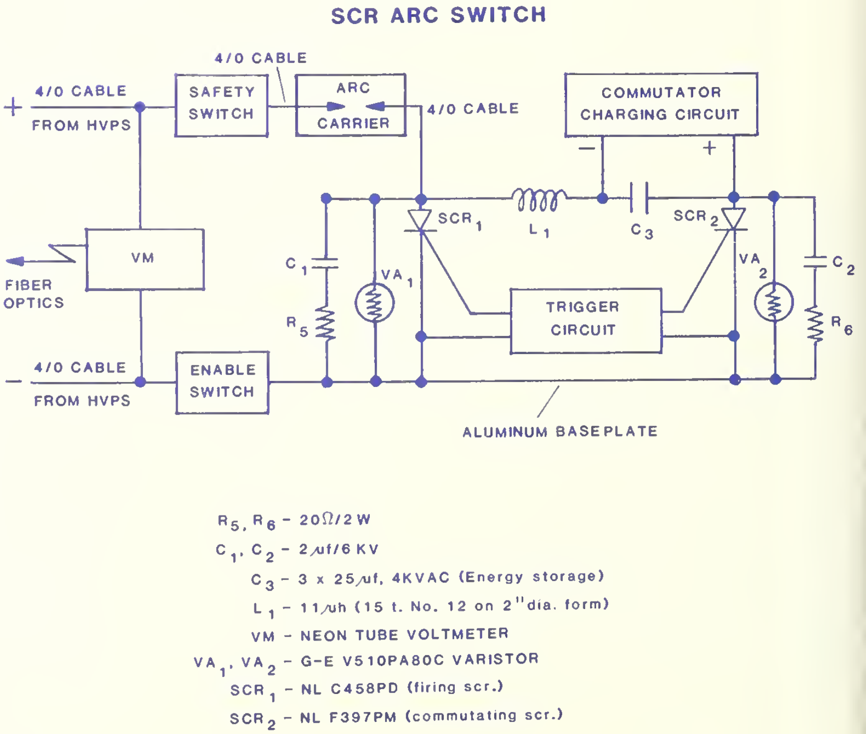


Figure 9—Part of the battery building interior. The series resistor carbon rod array is on the left. The movable tap is on the left side of the resistor array. The safety switches are covered for safety, and the use of the flag in the photograph of figure 8 is apparent.

The series current-setting resistor (R_4, fig. 6, and shown in the photograph of fig. 9 on the left side) is composed of 50 welding rods clamped by brass clamps in a series arrangement. The rod size was calculated by simultaneously considering the resistance of an individual rod, the temperature rise of the rod during a maximum current experiment, and the consequent thermally caused expansion of the rod. The resistance of commercially available arc welder cutting rod was juggled against an allowed thermal expansion of 0.1 mm for the rod. The result is the array of fifty 4.7-mm diameter rods each 61 cm long. There has been no breakage due to thermal stress (although we find that the rods do not bend readily). The clamps are not rigidly fastened to the frame on which the resistor is constructed.

The arc switch and its accompanying circuitry are shown in figures 10 and 11. An attempt to use a physical switch quickly convinced us that, although silicon controlled rectifiers (SCR's) with the needed reverse voltage and peak current capability were expensive, they would provide the fast and easily controlled switching that we needed. An SCR with a turn-on time on the order of 1 microsecond, turn-off on the order of 30 microseconds would meet our needs. The National NL-C458 1,400-volt, 2,000-amp fast-switching device was selected.

SCR's must be protected against electrical environment excesses: current rate of change (di/dt), rate of voltage application across the device (dv/dt), excess voltage across the device, and excessive current (Gutzwiller 1961;



R_5, R_6 - 20Ω/2 W
C_1, C_2 - 2µf/6 KV
C_3 - 3 x 25µf, 4KVAC (Energy storage)
L_1 - 11µh (15 t. No. 12 on 2"dia. form)
VM - NEON TUBE VOLTMETER
VA_1, VA_2 - G-E V510PA80C VARISTOR
SCR_1 - NL C458PD (firing scr.)
SCR_2 - NL F397PM (commutating scr.)

Figure 10—SCR arc switch assembly (ref. fig. 1). The use of components is discussed in the text.

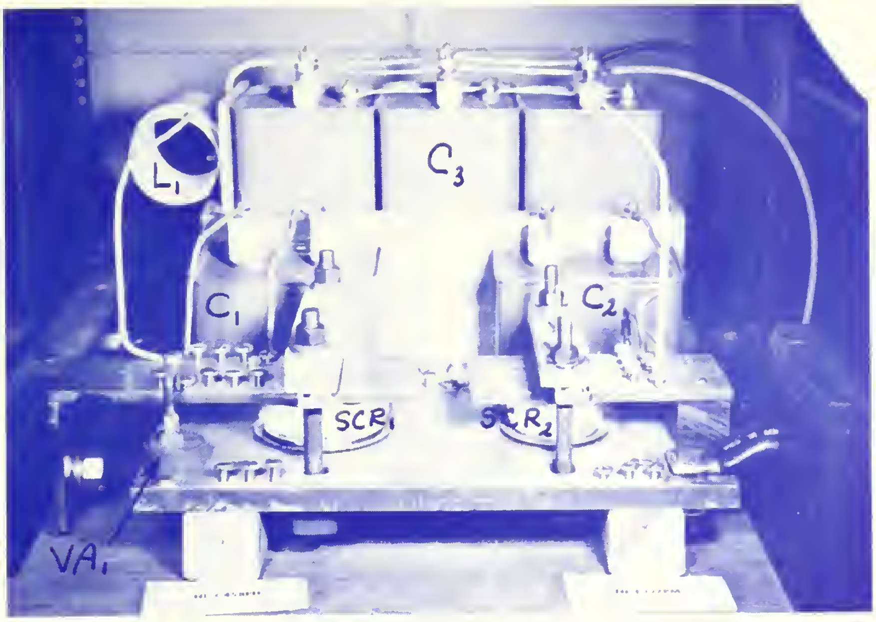
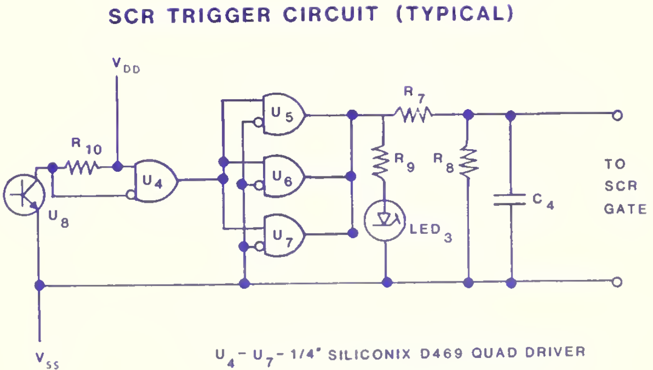


Figure 11—SCR switch assembly (ref. fig. 10). The "hockey puck" SCR's are clamped to the aluminum baseplate heatsink under approximately 1 ton of force each by the crossbars shown.

Telefunken 1981). Protection against excessive di/dt for the arc switch is provided by the inductance of the high-voltage power supply leads, which is several microhenries; dv/dt is limited by the elements R_5 and C_1. Voltage across the device is limited by the power supply voltage, but possible spikes due to "inductive kicks" or induced voltage spikes from outside the circuit are limited by VA_1. Current is limited by the high-voltage power supply resistor, R_4. SCR's, once triggered ("fired"), must be turned off by external means. The usual method of commutation for dc circuits is to provide a current pulse in opposition to the current flow through the SCR. The pulse must be applied when the commutated SCR's gate is off, and must have sufficient energy to "hold off" the current flow long enough to meet the turn-off time specifications of the commutated SCR. Our circuit commutates the arc switch by a second SCR and an energy storage capacitor. The commutator, SCR_2, switches the energy stored in C_3 through SCR_1, "bucking" the arc current and turning SCR_1 off. The energy storage capacitor is especially constructed so as to have very low inductance. SCR_2 is protected against di/dt by L_1, which also limits the reverse di/dt of SCR_1. Spikes for SCR_2 are limited by VA_2, and dv/dt by R_6 and C_2.



U_4 - U_7 - 1/4" SILICONIX D469 QUAD DRIVER
U_8 - G-E L14G3 PHOTOTRANSISTOR
R_7 - 30Ω
R_8 - 500Ω
R_9 - 1KΩ
R_{10} - 5.6MΩ
C_4 -.003µf
LED_3 - 10ma RED LED

Figure 12—Schematic diagram of the SCR trigger circuit (ref. fig. 10). The switch and commutating SCR's have identical triggers.

Figure 12 is the schematic for the gate trigger circuit used for both SCR_1 and SCR_2 of figure 10. Necessary current rate-of-rise limiting is provided by R_8 and C_4 and gate current limiting by R_7. LED_3 is used for testing. The quad driver circuit shown here and in the drivers and receivers for the fiber optics (fig. 3A,B) has proven very versatile and inexpensive. The fiber optics detector used in the SCR triggers is the same as that of figure 3B.

The manual safety switch, figure 13 and on the left in figure 15, has the pneumatic interlock shown in figure 4 as the "safety bleed valve." The arc enable switch is diagrammed in figure 14 and is on the right in figure 15. These switches are, as shown in figure 10, in series with the power supply, the arc, and the arc switching SCR. Long throws are used in these safety switches to ensure that current to the arc can be interrupted if SCR_1 cannot be commutated. The manual switch opens to a 30-cm gap, the arc enable switch to a 20-cm gap. Large brass disks are used on these switches to give a large, low-resistance contact surface, provide a large heat capacity, and ensure that in an emergency the arc will stay between the electrodes as the switch is opened. The tube that can be seen in the manual safety switch chamber directs freon gas into the gap if necessary. It has not been used to date, although the safety aspect of the switches is proved in practice.

The commutating energy storage capacitor, C_3, is charged by the dc-dc converter of figures 4 and 16. This device is a "black box" that takes 12-volt dc input and give a 400-volt dc output. The converter power is switched by the controller using RL_1, and the charging circuit closed b RL_2. RL_2 limits the initial charging current (theoretically infinite when the capacitor has zero charge), protecting th converter. Because the converter's internal circuitry is no known, back voltage protection is given it by D_2 and D_3.

The voltmeter detail for both the arc switch and the commutator power supply is shown in figure 17. The use of series-connected neon lamps in this circuit provides a convenient feedback through the fiber optics interface to the computer for verifying the presence of these voltages before SCR-triggering signals are given. A quick-glance visual check is also easy. A D'arsonval movement voltmeter, not shown, is also used on the commutator supply

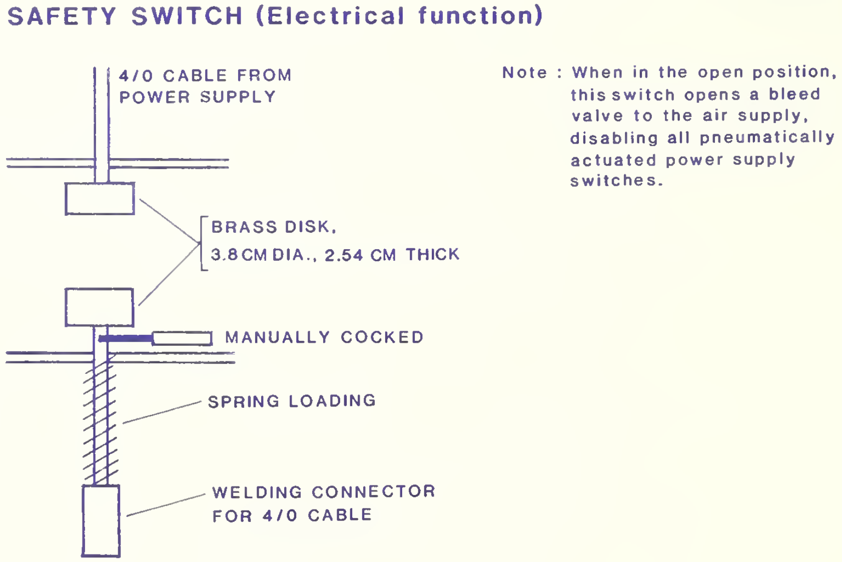


Figure 13—The manual safety switch (ref. figs. 1, 10). The long throw is necessary to interrupt the dc arc.

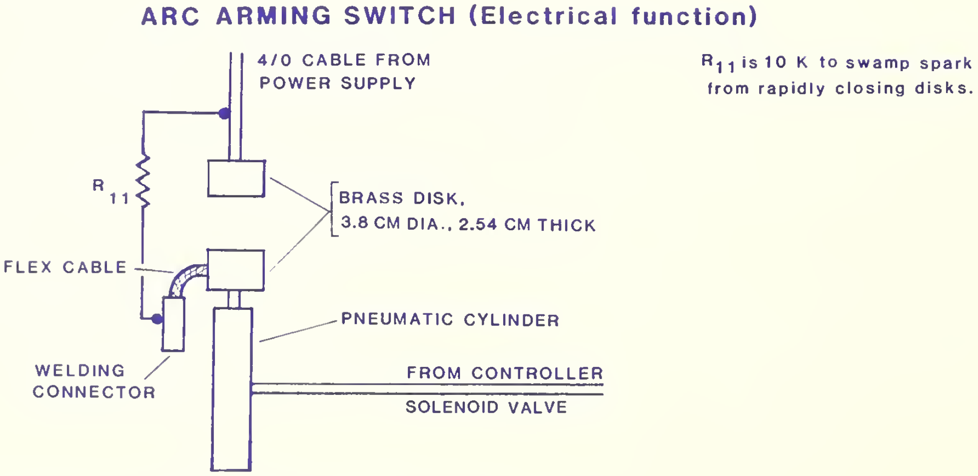


Figure 14—The pneumatic arc arming switch (ref. figs. 1, 4, 10).

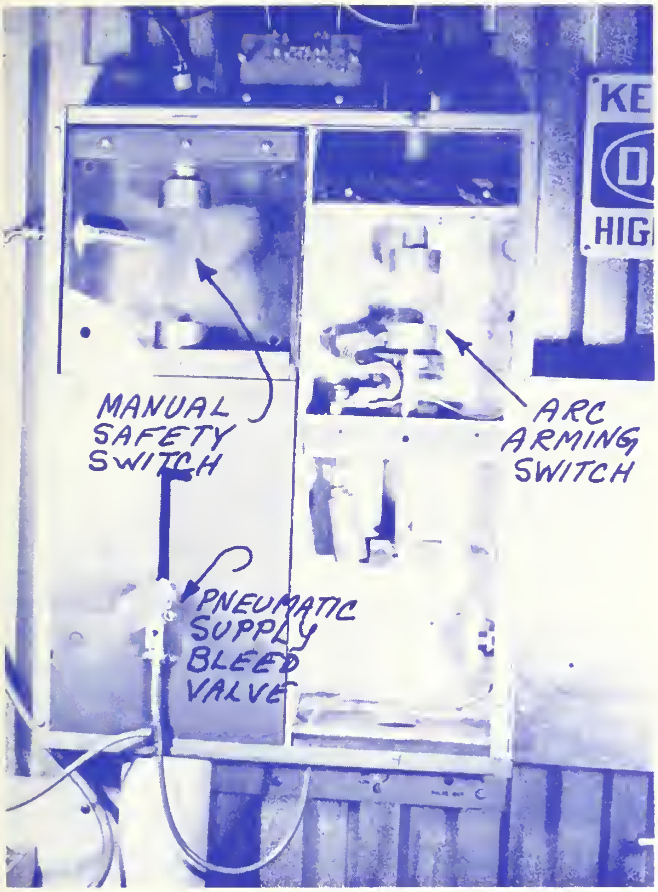


Figure 15—Arc arming switch (ref. fig. 14) (right) and the manual safety switch (ref. fig. 13) (left). Note the pneumatic supply bleed valve just below the switch actuating handle. The high-voltage power supply voltmeter (ref. fig. 17) can just be seen on top of the box containing the switches.

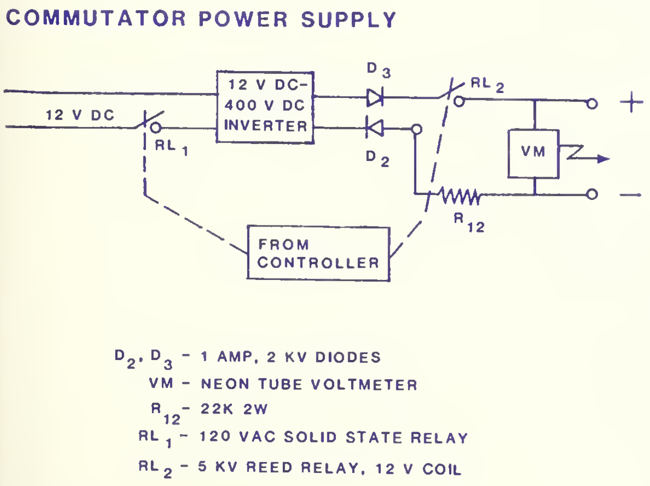


Figure 16—Commutator capacitor charging power supply (ref. fig. 4).

for further visual confirmation of the commutating voltage, and to make sure visually that, after the arc cycle is finished, no charge remains on commutating capacitor C_3.

The arc carrier, diagrammed schematically in figure 18, is a simple arrangement for holding the copper-clad carbon arc welder cutting electrodes.

The copper cladding is removed from the rod for 5 cm or so down from the conical tip so that a minimum of copper will be involved in the arc (there is probably some small contamination). Two clamps, not shown on the diagram, hold the 4-mil tungsten wire that initiates the arc.

Fundamental measurements of the arc parameters include current in the arc circuit and voltage across the arc. Current is usually measured either by measuring the voltage drop across a resistance or, for pulses, by a transformer. Although elaborate precautions are not usually necessary for measuring the moderately high voltages used in the arc generator, the unusually low source impedance (current-source capacity) of the battery supply calls

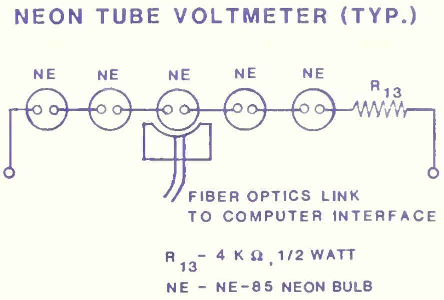


Figure 17—Neon tube voltmeter. The arc circuit (ref. figs. 10, 15) and the commutator power supply (ref. fig. 16) include one of these devices.

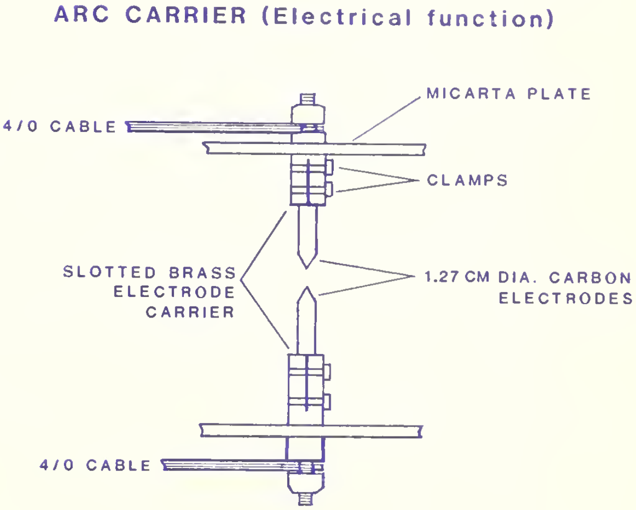


Figure 18—Arc generator electrode construction (ref. fig. 10).

for more than usual care with respect to grounding and measurement procedures. Large current flows result in large voltage drops across what can usually be considered negligible resistances. To avoid potentially dangerous ground loops, we have gone to great pains to isolate the high-current circuit from ground. To make current measurements with grounded apparatus would defeat this end.

Fortunately, the high currents give us a solution to this problem. A current flow generates a magnetic field which, if measured with attention to the geometry of the measurement, allows calculation of the current causing it. We found an inexpensive Hall-effect device for measurement of magnetic fields. A test verified that the rise time of the device and its associated circuitry (fig. 19A,B) was at least an order of magnitude better than the turn-on time of the switch.

We had an isolation amplifier on hand for voltage measurement. This amplifier had a rise time that was too slow to be used in a current measurement, although we might have done so. It could, however, be used in calibration and, in use of the generator, phenomena with tens-of-milliseconds and longer timescales. A simple resistor voltage divider was constructed to accommodate the voltage range of arc operation, and the assembly calibrated with a power supply and digital voltmeter. The voltage-measuring circuit is not diagrammed because it is straightforward. The luminosity measurement is done with a simple solid-state photovoltaic photodiode (EG&G SD-100).

The series resistor was accurately measured with a Wheatstone bridge, and the current device calibrated using the arc generator with the arc gap shorted. Measurement precision is 1 percent or better depending on the readout device for the current and voltage circuits. Accuracy depends on the readout device as well. We are not asking for better than 2 to 3 percent accuracy in the experimental design, and will be doing well to get that with the variables associated with real fuels in the ignition testing.

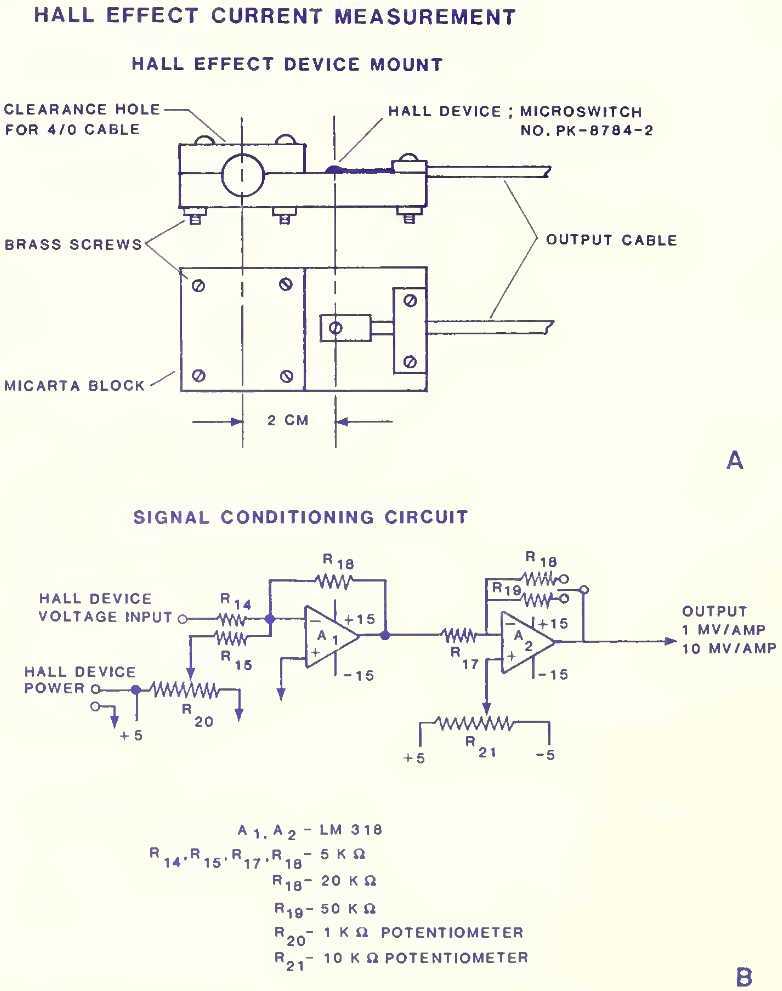


Figure 19—Hall-effect current measurement device (ref. fig. 1). The use of the device is apparent from part A of the figure. The Hall device is held at a known distance from the center of the cable and measures the magnetic field generated by the current flow.

OPERATION

The operation of the arc generator is under computer control. The sequence of steps is as follows:

1. The program is started.
2. The program prompts the operator to put a wire in the arc gap.
3. The program prompts the operator to close the manual safety switch.
4. The operator is prompted to turn on the main air supply switch.This turns on the controller power supply.
5. The operator is asked for the desired arc duration (> 20 ms, < 1 sec).
6. The program now assumes control of the operation.
7. The commutator power supply is energized.
8. The commutator charging switch is closed.
9. When the commutator is charged, the high-voltage switches are closed; otherwise abort.
10. When the high-voltage switches are closed, the arc enable switch is closed; otherwise abort.
11. The program waits for a manual firing command; otherwise aborts after 30 seconds.
12. The commutator charging and power supply switches are opened.
13. The arc SCR is triggered.
14. After the requested delay (step 5), the commutating SCR is triggered.
15. All switches are opened.
16. After a 2-sec delay, the commutator charging switch is closed (to fully discharge the commutating capacitor).
17. Success is announced, and the operator asked to turn off the air supply and open the manual safety switch.
18. The program returns to step 1 for the next shot.
19. If an abort has occurred, the commutator capacitor is discharged, and an abort is announced.
20. The program returns to start.

The program for carrying out this procedure is listed in the appendix.

PERFORMANCE

Typical results of operation of the arc generator are shown in figures 20 and 21. The upper trace of figure 20 is a current measurement with a 1.21-ohm series resistor and a shorted gap. There is a very gradual increase in the current with time due to heating of the resistor. In this example, the resistor was dissipating 96 kw and the total energy loss in the resistor was 3,368 Joules. The spike on the stopping transient is caused by the dumping of charge by the commutating capacitor, C_3. Figure 21 shows the result of recording the current flow and voltage across a typical arc of 6 cm length. This record, as well as the previous one, demonstrates the poor response of the isolation amplifier

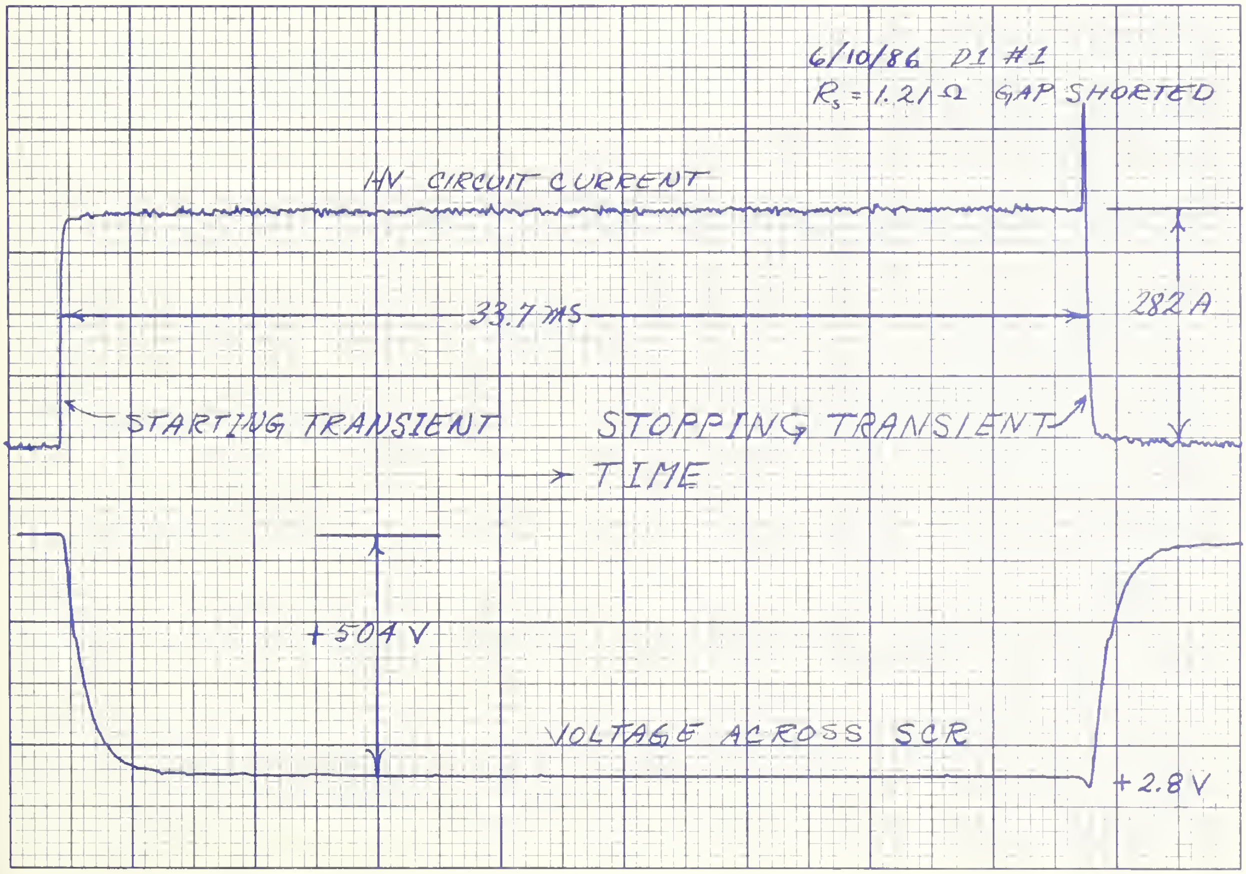


Figure 20—Current in the arc circuit and voltage across SCR_1 (ref.fig. 10) for a nominal 35 ms duration pulse. The arc gap was shorted with battery jumper cables for this test.

used for voltage measurement. The initial current pulse and subsequent fall in current are due to the tungsten wire heating and burning through. Copious electrons are provided by this mechanism, and, when the wire burns through, the arc strikes in the ionized channel left by the wire. The arc grows in diameter (according to our models), with a consequent increase in current flow, until an apparent equilibrium is reached. The power in the arc is about 24 kw, and the energy dissipation about 1,000 Joules. We are presently investigating the electrical characteristics of the arc and the details of arc striking.

Altogether, we are pleased with the performance of the arc generator. It meets the design criteria, especially those generated by safety considerations. With only two exceptions, the switching and control circuits have performed well. The cause of the exceptions has been corrected. The only nagging problem with the system is periodic cleaning of the power supply switches. Because we will be finished with the experiment in the near future, we will not plate the electrodes, which would solve this problem.

REFERENCES

Cobine, J. D. 1958. Gaseous conductors. Mineola, NY: Dover Publications. 606 p.

Fuquay, D. M.; Taylor, A. R.; Hawe, R. G.; Schmidt, C. W., Jr. 1972. Lightning discharges that started forest fires. Journal of Geophysical Research. 77(12): 2156-2158.

Fuquay, D. M.; Baughman, R. G.; Latham, D. J. 1979. A model for predicting lightning-fire ignition in wildland fuels. Res. Pap. INT-217. Ogden, UT: U.S. Department of of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Gutzwiller, F. W. 1961. Silicon controlled rectifier manual. 2d ed. Auburn, NY: General Electric Corporation. 227 p.

King, L. A. 1961. The voltage gradient of the free-burning arc in air or nitrogen. Report No. G/XT172. Surrey, England: The British Electrical and Allied Industries Research Association. 16 p.

Latham, D. J. 1979. Progress toward locating lightning fires. Res. Note INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 6 p.

Latham, D. J. 1980. A channel model for long arcs in air. The Physics of Fluids. 23(8): 1710-1715.

Latham, D. J. 1986. Anode column behavior of long vertical air arcs at atmospheric pressure. IEEE Transactions on Plasma Science. PS-14(3): 220-227.

Telefunken. 1981. Leistungshalbleiter Frequenz-thyristoren. Somerville, NJ: AEG-Telefunken Co. [Catalog.]

Uman, M. A. 1984. Lightning. Mineola, NY: Dover Publications. 290 p.

Wilson, R. A. 1985. Observations of extinction and marginal burning states in free burning porous fuel beds. Combustion Science and Technology. 44: 179-193.

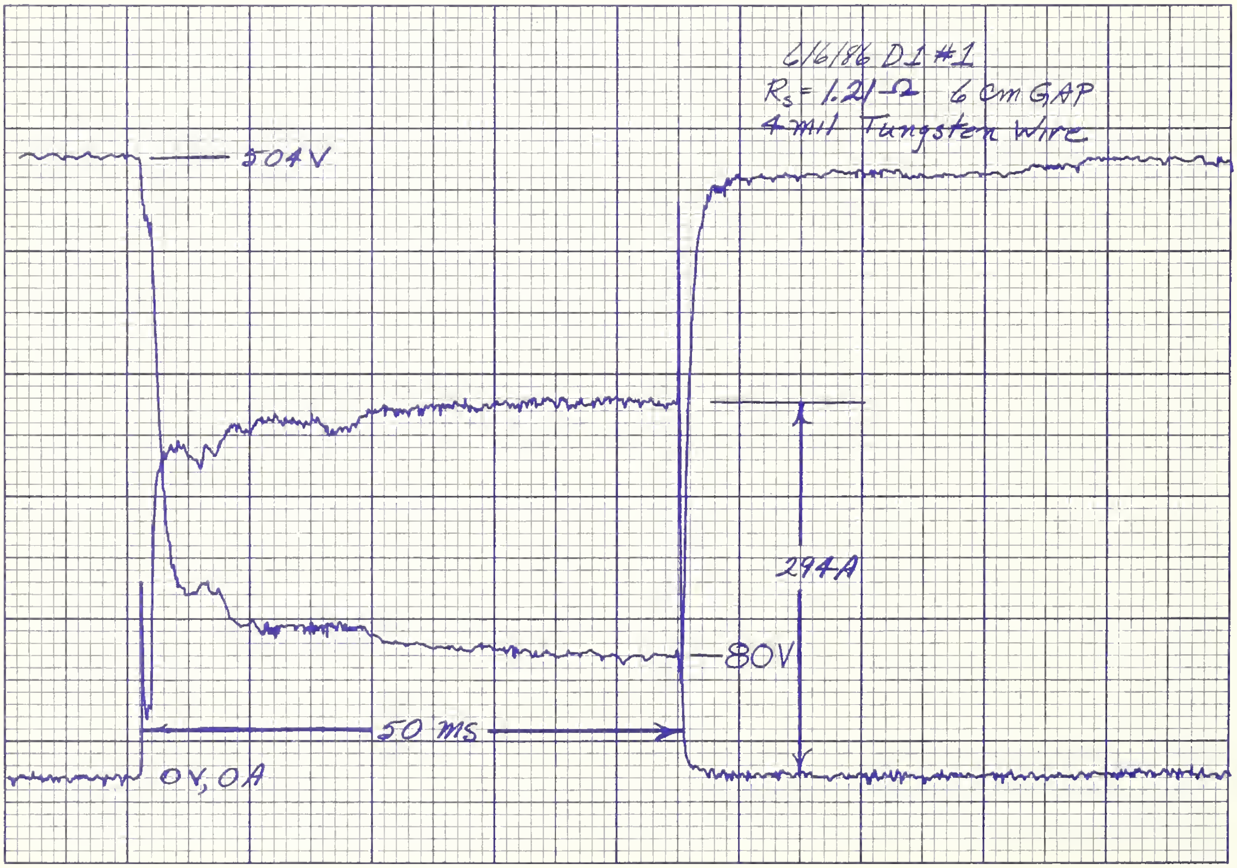
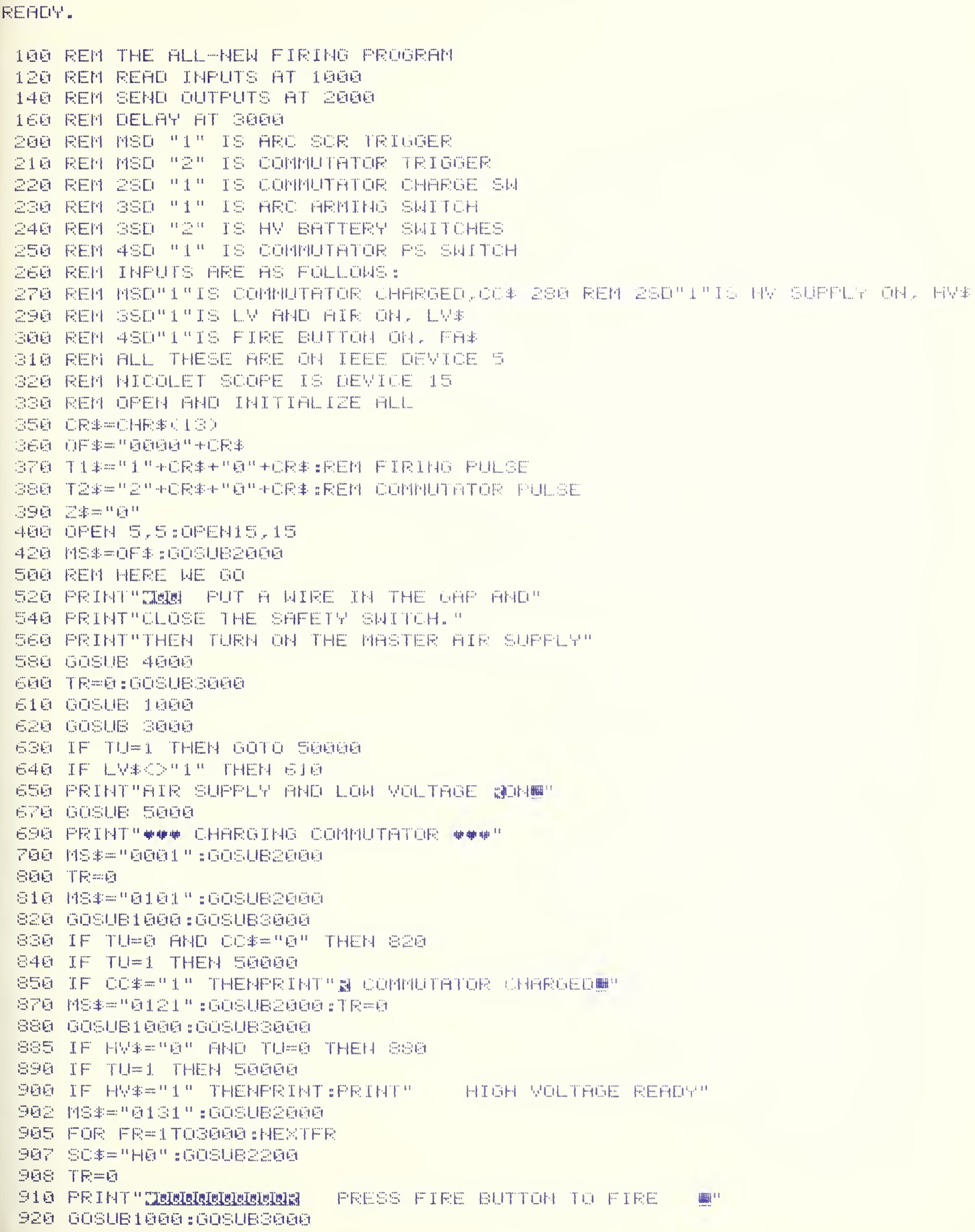


Figure 21—Current in the arc circuit and voltage across the arc gap (ref. fig. 10) for a nominal 50 ms duration pulse.

APPENDIX: OPERATING SEQUENCE OF ARC GENERATOR



```
READY.

 100 REM THE ALL-NEW FIRING PROGRAM
 120 REM READ INPUTS AT 1000
 140 REM SEND OUTPUTS AT 2000
 160 REM DELAY AT 3000
 200 REM MSD "1" IS ARC SCR TRIGGER
 210 REM MSD "2" IS COMMUTATOR TRIGGER
 220 REM 2SD "1" IS COMMUTATOR CHARGE SW
 230 REM 3SD "1" IS ARC ARMING SWITCH
 240 REM 3SD "2" IS HV BATTERY SWITCHES
 250 REM 4SD "1" IS COMMUTATOR PS SWITCH
 260 REM INPUTS ARE AS FOLLOWS:
 270 REM MSD"1"IS COMMUTATOR CHARGED,CC$ 280 REM 2SD"1"IS HV SUPPLY ON, HV$
 290 REM 3SD"1"IS LV AND AIR ON, LV$
 300 REM 4SD"1"IS FIRE BUTTON ON, FA$
 310 REM ALL THESE ARE ON IEEE DEVICE 5
 320 REM NICOLET SCOPE IS DEVICE 15
 330 REM OPEN AND INITIALIZE ALL
 350 CR$=CHR$(13)
 360 OF$="0000"+CR$
 370 T1$="1"+CR$+"0"+CR$:REM FIRING PULSE
 380 T2$="2"+CR$+"0"+CR$:REM COMMUTATOR PULSE
 390 Z$="0"
 400 OPEN 5,5:OPEN15,15
 420 MS$=OF$:GOSUB2000
 500 REM HERE WE GO
 520 PRINT"▒▒▒  PUT A WIRE IN THE GAP AND"
 540 PRINT"CLOSE THE SAFETY SWITCH."
 560 PRINT"THEN TURN ON THE MASTER AIR SUPPLY"
 580 GOSUB 4000
 600 TR=0:GOSUB3000
 610 GOSUB 1000
 620 GOSUB 3000
 630 IF TU=1 THEN GOTO 50000
 640 IF LV$<>"1" THEN 610
 650 PRINT"AIR SUPPLY AND LOW VOLTAGE ▒ON█"
 670 GOSUB 5000
 690 PRINT"♥♥♥ CHARGING COMMUTATOR ♥♥♥"
 700 MS$="0001":GOSUB2000
 800 TR=0
 810 MS$="0101":GOSUB2000
 820 GOSUB1000:GOSUB3000
 830 IF TU=0 AND CC$="0" THEN 820
 840 IF TU=1 THEN 50000
 850 IF CC$="1" THENPRINT"▒ COMMUTATOR CHARGED█"
 870 MS$="0121":GOSUB2000:TR=0
 880 GOSUB1000:GOSUB3000
 885 IF HV$="0" AND TU=0 THEN 880
 890 IF TU=1 THEN 50000
 900 IF HV$="1" THENPRINT:PRINT"    HIGH VOLTAGE READY"
 902 MS$="0131":GOSUB2000
 905 FOR FR=1TO3000:NEXTFR
 907 SC$="H0":GOSUB2200
 908 TR=0
 910 PRINT"▒▒▒▒▒▒▒▒▒▒▒▒   PRESS FIRE BUTTON TO FIRE    █"
 920 GOSUB1000:GOSUB3000
```

APPENDIX (Con.)

```
930 IF FA$="0" AND TU=0 THEN 910
940 IF TU=1 THEN 50000
950 IF FA$="1" THEN GOSUB 30000
960 GOTO 40000
999 END
1000 REM READ INPUTS
1020 CC$=Z$
1040 LV$=Z$
1060 HV$=Z$
1080 FA$=Z$
1200 INPUT#5,I$
1220 CC$=MID$(I$,1,1)
1240 HV$=MID$(I$,2,1)
1260 LV$=MID$(I$,3,1)
1280 FA$=MID$(I$,4,1)
1999 RETURN
2000 REM SEND MS$ TO COUPLER
2020 PRINT#5,MS$
2040 MS$=""
2099 RETURN
2200 REM SEND TO NICOLET
2220 PRINT#15,SC$
2230 SC$=""
2999 RETURN
3000 REM TIME DELAY
3020 TU=0
3040 IF TR=0 THEN TI$="000000"
3050 IF TI$<"000030" THEN TR=1:RETURN
3060 TU=1
3070 TR=0
3999 RETURN
4000 REM GET A SINGLE KEY AND INTERPRET
4010 KY$=""
4020 PRINT:PRINT"▓   G TO CONTINUE, SPACE TO STOP    ▓":PRINT
4040 GET KY$:IF KY$=""THEN4040
4060 IF KY$="G" THEN RETURN
4080 IF KY$=" "THEN 50000
4100 GOTO 4040
4999 REM END OF KEYIN
5000 REM CALCULATE DELAY NUMBER
5020 PRINT:INPUT"  DELAY IN MS";DE
5040 DE=INT((DE-19.35)/1.079)
5060 IF DE<0 THENPRINT" DELAY TOO SHORT":GOTO 5020
5999 RETURN
30000 REM TURN OFF COMMUTATOR AND FIRE
30020 REM DE IS THE DELAY NUMBER
30040 MS$="0030":GOSUB2000
30060 FOR DD=1 TO 10:NEXT
30080 PRINT#5,T1$;
30100 FOR DL=1TODE:NEXT
30120 PRINT#5,T2$;
30140 RETURN
40000 REM SUCCESSFUL OPERATION
40020 MS$=OF$
40030 GOSUB 2000
40040 PRINT"▓▓▓▓▓▓▓  SUCCESSFUL SHOT   ▓"
40045 GOSUB51000
```

APPENDIX (Con.)

```
 40050 GOSUB 4000
 40060 RUN
 50000 REM UNCONDITIONAL QUIT
 50100 PRINT"▒▒▒▒▒▒▒▒       OPERATION ABORTED       ▒"
 50110 GOSUB1000
 50120 IF TU=1 THEN PRINT "▒   DUE TO TIMEOUT▒"
 50140 IF CC$=Z$ THEN PRINT"   COMMUTATOR NOT CHARGED"
 50160 IF LV$=Z$ THEN PRINT"   AIR OR LOW VOLTAGE NOT ON"
 50180 IF HV$=Z$ THEN PRINT"   HIGH VOLTAGE NOT ON"
 50200 MS$=OF$
 50220 GOSUB 2000
 50240 GOSUB 51000
 50300 CLOSE 5:CLOSE 15
 50999 END
 51000 REM BLEED COMMUTATE CAPACITORS
 51020 REM ALLOW HVPS SWITCHES TO OPEN
 51040 FOR KL=1TO3000:NEXT
 51050 PRINT:PRINT"  ▒ BLEEDING COMMUTATOR ▒":PRINT
 51060 MS$="0100"
 51080 GOSUB2000
 51100 TR=0
 51120 GOSUB 3000
 51140 IF TU=0 THEN 51120
 51145 TU=0
 51160 MS$=OF$
 51180 GOSUB 2000
 51200 RETURN
 59999 END
READY.
```

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

June 1987
Intermountain Research Station
324 25th Street
Ogden, UT 84401

nited States
epartment of
griculture

orest Service

**ntermountain
esearch Station**

esearch Note
NT-367

Mountain Pine Beetle Selection of Dwarf Mistletoe and Comandra Blister Rust Infected Lodgepole Pine

Lynn A. Rasmussen[1]

ABSTRACT

Pairs of similar-size lodgepole pine—one attacked by mountain pine beetles and the other not attacked—were compared as to the degree of dwarf mistletoe and comandra blister rust infection they had. The data showed some evidence (one forest had a significant difference) that beetles chose to attack trees with heavier infections of comandra blister rust. On the other hand, due to the high incidence of dwarf mistletoe in the areas examined, comparisons of beetle/dwarf mistletoe interactions were difficult.

KEYWORDS: *Dendroctonus ponderosae, Arceuthobium americanum, Cronartium comandrae, Pinus contorta*

INTRODUCTION

Incidence of bark beetle infestation has long been associated with weakened, decadent, or overmature trees. Consequently, most investigations into the causes of outbreaks of bark beetles have been concerned with factors that weaken the tree, thereby making invasion and killing of the tree by beetles possible. However, Amman (1969, 1972), Cole and Amman (1969), and Roe and Amman (1970) found that large-diameter lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) with thick phloem make possible the buildup of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) populations and, hence, large infestations of this beetle in lodgepole pine forests. Furthermore, thickness of phloem, the food source of developing larvae, is closely related to positive factors of host vigor (D. M. Cole 1973). These observations of the variables that result in increased beetle populations are in direct opposition to the theory that weak trees and mountain pine beetle epidemics go together.

A first step in the resolution of this controversy is to determine if mountain pine beetles attack lodgepole pine on the basis of degree of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) and comandra blister rust (*Cronartium comandrae* Pk.) infection.

Dwarf mistletoe is a parasitic seed plant that has separate male and female plants. The plant consists of an aerial portion and a network of absorbing strands that are hidden in, and obtain nourishment from, the cortex and xylem of the host tree (Hawksworth and Dooling 1984). During the initial years of infection, tree growth in the immediate area of the mistletoe strands is stimulated, resulting in wide annual rings and thick phloem. Ultimately, high dwarf mistletoe infections retard growth of the host and may lead to premature death of the tree.

Studies directed specifically at the incidence of mountain pine beetle infestation in lodgepole pine trees infected by dwarf mistletoe are few in number, although the literature frequently indicates that this interaction may be important. Parker and Stipe (1974) found that the mistletoe infection rate of lodgepole pine ranged from 54 to 85 percent of the trees in three study areas, and that trees with a mistletoe rating of 4, 5, or 6 (Hawksworth's 1977 system, see explanation in next section) ranged from 19 to 46 percent for the three stands. Trees killed by the beetle had mistletoe ratings averaging between 3 and 4. They interpreted their findings as indicative that mountain pine beetles select mistletoe-infected trees. However, the large amount of mistletoe infection in the stands makes positive conclusions about the interaction of beetle and dwarf mistletoe difficult.

McGregor (1978) reported that lodgepole pine stands with the least mistletoe infection suffered the greatest mortality from mountain pine beetle infestations.

---

[1] Biological technician, Mountain Pine Beetle Population Dynamics esearch work unit, Forestry Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

Roe and Amman (1970) observed that dwarf mistletoe infection was highest and losses to the mountain pine beetle were lowest in the *Abies lasiocarpa/Vaccinium scoparium* habitat type. However, an overriding factor with respect to reduced losses in this habitat type is climate. Much of this habitat type is at high elevations; consequently, the effect of climate on beetle populations could have significantly reduced beetle survival and, hence, losses to the beetle. Roe and Amman (1970) observed that the phloem thickness at breast height was significantly thinner ($P = 0.05$) in trees that had medium to heavy mistletoe crown infections when compared to trees with no infection. Therefore, the association of mountain pine beetles with dwarf mistletoe infected trees could prove detrimental to the beetle population in that brood production could be below the replacement rate. In contrast, Hawksworth and others (1983) in a Colorado study report a much less significant relationship between lodgepole pine phloem thickness and dwarf mistletoe.

Comandra blister rust, caused by the fungus *Cronartium comandrae* Pk., also is a serious disease affecting lodgepole pine (Johnson 1986). The disease alternates between herbaceous comandra plants and pine hosts. The infections on pine develop in 2 to 4 years into spindle-shaped cankers. The cankers enlarge, eventually girdling the infected branch or stem. Girdling stem cankers result in spike tops and eventually can cause tree death. The larger lodgepoles, usually those in the higher crown classes, are the most frequently damaged (Krebill 1975). These are the same trees favored by mountain pine beetles.

Comandra plants generally occur as aggregated groups among sagebrush (Brown 1977), and the proximity of comandra plants to lodgepole pine stands can directly influence the severity of infection (Krebill 1965). In many stands, the heaviest amounts of infection tend to occur near the edge of stands (Brown 1977), a habit also characteristic of endemic populations of mountain pine beetles (Washburn and Knopf 1959).

Because most of the lodgepole pine stands infested with mountain pine beetles in the Intermountain area are to some degree infected with dwarf mistletoe or comandra blister rust or both, there is a need for knowledge of the relationship of these diseases to beetle dynamics. Therefore, a study was designed to assess the interaction of mistletoe and comandra blister rust on endemic beetle attack behavior on the Shoshone National Forest, WY, and Sawtooth National Forest, ID, where endemic populations of beetles were located.

Endemic infestations were selected because there is an opportunity to study tree selection behavior more closely than in outbreak situations where large numbers of trees are being attacked, resulting in fewer live trees for the beetle to choose from.

MATERIALS AND METHODS

Mountain pine beetle attack behavior was determined once emerging beetles started attacking green trees in early August. We conducted a daily search of each area to locate and mark newly infested trees. Only trees that were successfully mass attacked were used. We rated these trees as to the degree of dwarf mistletoe infection, using Hawksworth's (1977) 6-class system, and the degree of comandra blister rust infection using Brown's (1977) 8-class system. In Hawksworth's system the live crown is divided into thirds, each third being rated from 0 (no infection) to 2 (heavy infection). The ratings of each third are added to obtain mistletoe rating for the entire tree. In Brown's system, the crown, both live and dead portions, is divided into thirds, and the most damaging canker in each third is rated as to girdling or nongirdling on a scale with highest ratings in lowest third. The ratings from each third are then added to obtain the total tree rating.

We then located the nearest tree uninfested by the beetle and of similar size, plus or minus 1 inch diameter at breast height (d.b.h.). We rated the uninfested tree as to degree of mistletoe and comandra blister rust infection. Additional data collected from these trees included d.b.h., phloem thickness, annual increment for the previous 10 years, and number of mistletoe-caused brooms.

RESULTS AND DISCUSSION

Although the data sets are small, they represent 100 percent of the mountain pine beetle-infested trees that could be located within a drainage in each Forest. At the time, the Shoshone infestation was characterized by small, scattered groups of three to four trees each, whereas the Sawtooth infestation consisted of a single group of 18 infested trees. The stands in both study areas were almost pure lodgepole pine, with a minor component of subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and aspen (*Populus tremuloides* Michx.).

Using a paired T-test, no significant differences were found in any data sets. Table 1 shows only small differences between the trees attacked by mountain pine beetles and the nearest uninfested tree of similar size. Attacked trees had, on the average, higher comandra blister rust

Table 1—Paired T-test comparison[1] of pairs of lodgepole pine trees—one attacked by mountain pine beetles, the other the nearest similar-size tree not attacked

	Forest	
Comparisons	Shoshone	Sawtooth
Average rust rating		
Attacked	2.5	1.1
Unattacked	1.6	.2
Average mistletoe rating		
Attacked	5.6	6.0
Unattacked	5.8	5.7
Average number of mistletoe brooms		
Attacked	1.6	.8
Unattacked	1.7	.8
Average phloem thickness		
Attacked	.09	.10
Unattacked	.09	.10
Average 10-year growth		
Attacked	.022	.034
Unattacked	.020	.029

[1] None were significant at 0.05 level of probability.

Table 2—Chi-square test of number of trees infected with comandra blister rust and mistletoe on Shoshone and Sawtooth National Forests

	With comandra blister rust	No comandra blister rust	With mistletoe	No mistletoe	With brooms	No brooms
Shoshone trees:						
Attacked	19	7	26	0	14	12
Green	19	7	26	0	16	10
	[1]	[1]	[1]	[1]	[1]	[1]
Sawtooth trees:						
Attacked	6	12	18	0	8	10
Green	1	17	18	0	6	12
	$P < 0.05$	[1]	[1]	[1]	[1]	[1]

[1] Not significant.

ratings and were growing a little faster. There were little or no differences in mistletoe ratings, number of brooms, or in phloem thickness.

In comparing numbers of trees with and without mistletoe or comandra blister rust infection with a Chi-square test, we found only one case of a statistically significant difference. On the Sawtooth, six out of 18 beetle-attacked trees had a comandra blister rust infection, whereas only one of 18 unattacked trees had a comandra blister rust infection (table 2).

There appears to be some evidence that mountain pine beetles select lodgepole pine on the presence of comandra blister rust infection, at least on the Sawtooth National Forest. The high incidence of mistletoe in both forests makes comparisons of beetle/mistletoe interactions difficult. Additional evaluations of mountain pine beetle and tree pathogen interactions, particularly in endemic situations, are needed to determine the triggering mechanisms of epidemics.

REFERENCES

Amman, Gene D. 1969. Mountain pine beetle emergence in relation to depth of lodgepole pine bark. Res. Note INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Amman, Gene D. 1972. Mountain pine beetle brood production in relation to thickness of lodgepole pine phloem. Journal of Economic Entomology. 65: 138-140.

Brown, D. H. 1977. Management guidelines for lodgepole pine stands infected with comandra blister rust and dwarf mistletoe. Tech. Rep. R2-9. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Forest Insect and Disease Management, Rocky Mountain Region. 21 p.

Cole, Dennis M. 1973. Estimation of phloem thickness in lodgepole pine. Res. Pap. INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Cole, Walter E.; Amman, Gene D. 1969. Mountain pine beetle infestations in relation to lodgepole pine diameters. Res. Note INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 7 p.

Hawksworth, F. G. 1977. The 6-class dwarf mistletoe rating system. Gen. Tech. Rep. RM-48. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

Hawksworth, F. G.; Dooling, O. J. 1984. Lodgepole pine dwarf mistletoe. For. Insect and Dis. Leafl. 18. Washington, DC: U.S. Department of Agriculture, Forest Service. 11 p.

Hawksworth, F. G.; Lister, C. K.; Cahill, D. B. 1983. Phloem thickness in lodgepole pine: its relationship to dwarf mistletoe and mountain pine beetle (Coleoptera: Scolytidae). Environmental Entomology. 12: 1447-1448.

Johnson, David W. 1986. Comandra blister rust. For. Insect and Dis. Leafl. 62 (rev.). Washington, DC: U.S. Department of Agriculture, Forest Service. 8 p.

Krebill, R. G. 1965. Comandra rust outbreaks in lodgepole pine. Journal of Forestry. 63: 519-522.

Krebill, R. G. 1975. Lodgepole pine's fungus-caused diseases and decays. In: Baumgartner, D. M., ed. Management of lodgepole pine ecosystems: Symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service: 377-405.

McGregor, Mark D. 1978. Management of mountain pine beetle in lodgepole pine stands in the Rocky Mountain area. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: Symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forestry, Wildlife and Range Experiment Station: 129-139.

Parker, D. L.; Stipe, L. E. 1974. Does the mountain pine beetle select and kill dwarf mistletoe-infected lodgepole pine? Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, State and Private Forestry, Insect and Disease Control Report. 12 p.

Roe, Arthur L.; Amman, Gene D. 1970. The mountain pine beetle in lodgepole pine forests. Res. Pap. INT-71. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 23 p.

Washburn, R. K.; Knopf, J. A. E. 1959. Mountain pine beetle conditions in the lodgepole pine stands of Forest Service Region 4. Unpublished paper. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Ogden, UT. 8 p. + maps.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

July 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-368

Carbohydrate Reserves in Nursery Stock—Effects of Cultural Practices

Debora A. Kennedy
James L. Clayton
Russell A. Ryker
Kathleen Geier-Hayes
John Sloan[1]

ABSTRACT

Planting stock grown at the Lucky Peak Nursery, U.S. Department of Agriculture, Forest Service, near Boise, ID, must be lifted after the winter chilling requirement is satisfied, but early enough in the spring that trees remain dormant. Trees may satisfy their chilling requirement by late fall or early winter and be lifted in December if weather conditions permit. These trees require storage of several months prior to planting. Trees also may be lifted in early spring, but they require storage of several weeks before Intermountain forest planting sites are free of snow. Trees lifted from late fall (November 1) to early spring (March 15) seem better able to maintain their vigor during periods of cold storage than do trees lifted earlier in the fall or later in the spring.

KEYWORDS: total nonstructural carbohydrate, ponderosa pine, lodgepole pine, fertilizer treatment, lift date, moisture stress

When following previously developed procedures for lifting, handling, and planting, survival of planting stock at the Forest Service's Lucky Peak Nursery (near Boise, ID), has generally been successful. However, tree vigor and growth following outplanting are affected by other nursery cultural practices such as irrigation and fertilization regimes. One concern at Lucky Peak is that food reserves necessary for good growth following outplanting are diminished by either long storage time during dormancy or during relatively short storage when trees are not completely dormant. In addition, the effects of various nursery cultural practices on food storage are unknown.

Krueger and Trappe (1967) documented a marked temporal pattern in concentration of total sugars and starch in seedling roots and tops during winter months. They found that sugars increase in concentration starting in November, reach a January peak nearly three times summer concentrations, then decrease steadily to a low level in May. Starch concentrations decrease during the winter sugar buildup, then increase rapidly in March to a mid-April peak. Ronco (1973) studied survival of field planted trees as a function of food reserves but was unable to find a correlation. However, he hypothesized that there must be some threshold level of food reserves required for seedling survival. Van den Driessche (1979) also suggested that a gradual respiratory depletion of stored sugars and starches might be implicated in poor survival and root growth potential. Various published studies have documented that seedling storage invariably results in food reserve depletion: See, for example, McCracken (1979) for starch and sugar declines in mugo and radiata pine through 18 weeks of cold storage, and Ritchie (1982) for descriptions of carbohydrate depletion in Douglas-fir during cold storage.

With the knowledge that storage time will result in depleted food reserves, and the expectation that this may be implicated in poor survival and vigor of planted seedlings, we undertook a study to investigate the effects of various nursery conditions and practices on food storage reserves at time of lifting. Specifically, we tested the hypotheses that nursery soil type, fertilizer treatments, irrigation schedules, lifting dates, and their interactions had an effect on total nonstructural carbohydrate concentration in ponderosa (*Pinus ponderosa* Laws.) and lodgepole pine (*Pinus contorta* Dougl.).

METHODS

We established the study in 1983 on two soils: a granitic sandy loam hereafter referred to as "light soil," and a

---

[1] Chemist, research soil scientist, research forester (retired), and foresters, respectively, located at the Intermountain Research Station's Forestry Sciences Laboratory, Boise, ID.

clay loam soil formed from basalt, referred to as "heavy soil." Prior to sowing, both soils had 1 inch (2.5 cm) of sawdust and 400 lb per acre (450 kg per ha) of 34-0-0 incorporated, followed by a 1-year crop of Austrian peas that were plowed under. Soils were fumigated with a mixture of methyl bromide and chloropicrin. Ponderosa and lodgepole pine seeds were sown in standard beds.

We established three watering regimes as follows:

W1 – Early morning plant water potential < -0.5 MPa during the growing season until the end of irrigation.

W2 – Plant water potential as above except from July 15 to September 1, when water potential could go to < -1 MPa.

W3 – As above, except from July 15 to September 1, potential could go to < -1.5 MPa.

Table 1—Fertilizer treatments. For the eight different fertilizer treatments, low N and high N refers to 99 lb per acre and 176 lb per acre (100 and 200 kg per ha) of nitrogen (34-0-0), respectively, incorporated prior to sowing, and three similar applications in the next two growing seasons. P refers to 60 lb per acre (66 kg per ha) of phosphorus (0-46-0) applied once

Fertilizer treatment	Milorganite (presown)		No Milorganite
	1,000 lb/acre	2,000 lb/acre	
1	low N		
2		high N	
3			low N
4			high N
5	low N, P		
6		high N, P	
7			low N, P
8			high N, P

W1 is referred to as the high water regime, W2 as intermediate, and W3 as the low water regime.

Eight fertilizer treatments and a control were assigned to each watering regime. The fertilizer treatments are shown in table 1.

Seedlings were lifted on six dates in fall 1984 and spring 1985. The first lift was September 18 to 21, followed by October 15 to 17, November 5 to 7, November 26 to 28, March 18 to 20, and April 8 to 10. The soil was frozen from mid-December through February, which is common for Lucky Peak Nursery.

Within 4 hours of lifting, five seedlings from each treatment were delivered to the laboratory, washed free of soil, and denatured in a microwave oven to prevent conversion of starches to sugar according to the method of Tiedemann and others (1984). Following the denaturing treatment, trees were ovendried at 150 °F (65 °C) for 24 hours, then ground in a Wiley mill to pass a 60-mesh screen. Duplicate subsamples of ground tissue were then analyzed for total nonstructural carbohydrate (TNC) by the method of da Silveira and others (1978). TNC includes all carbohydrates fixed by the plant that are generally considered available as food reserves.

Main effects and interactions were determined by analysis of variance for split plots. There were missing values, so covariates were added to the analysis of variance to estimate these values. The design of this study is illustrated in table 2.

RESULTS

Main plot comparisons show significant differences ($\alpha = 0.05$) in TNC concentration between species and soil types and between the three water regimes at $\alpha = 0.10$ (table 2). There were no significant interactions among the three factors—soil, water, and species. Comparison of the

Table 2—Analysis of variance of total nonstructural carbohydrate concentrations by soil types, watering regimes, species, lift dates, and fertilizer treatments

Source	DF	Sum of squares	F value	Pr > F
Main plot comparisons				
Soil	1	34,099.37	34.29	0.0279
Water	2	36,533.39	18.37	.0516
Species	1	24,962.22	25.10	.0376
Soil*Water	2	3,757.87	1.89	.3461
Soil*Species	1	695.23	.70	.4911
Water*Species	2	2,584.47	1.30	.4349
Error A	2	1,988.82		
Subplot comparisons				
Fertilizer	8	8,872.09	2.10	.0510
Soil*Fertilizer	8	4,476.75	1.06	.4045
Water*Fertilizer	16	6,954.62	.82	.6551
Species*Fertilizer	8	4,838.59	1.14	.3487
Error B	56	29,585.14		
Sub-subplot comparisons				
Lift Date	5	1,367,905.34	748.74	.0001
Soil*Lift	5	24,876.99	13.61	.0001
Water*Lift	10	16,960.85	4.64	.0001
Species*Lift	5	18,738.46	10.25	.0001
Fertilizer*Lift	40	14,886.44	1.02	.4129
Error C	464	169,541.38		

means (table 3) indicates that trees grown in the heavy soil had higher concentrations of TNC than trees grown in the lighter soil. These data are presented by lift date in figure 1. There were no significant differences in concentration between soils on the first and third lift dates. Trees grown under high water stress (low water regime) had significantly higher TNC concentration than other trees (table 3). These data are presented in figure 2, plotted by each lift date. Lodgepole pine trees had higher concentrations of TNC than ponderosa pine (table 3, fig. 3). This effect showed up for all lift dates except the first and was significant for all dates combined.

The subplot comparisons for fertilizer treatment indicate a significant main effect at $\alpha = 0.10$. One treatment, 2,000 lb (900 kg) of Milorganite plus subsequent annual high N additions, had a higher mean TNC concentration than did several other treatments including other high N, high N plus P, and one other Milorganite treatment. All four plots treated with Milorganite suffered from preemergent damping off disease, and tree densities were lower in these plots. These density differences may have confounded comparisons of fertilizer main effects and fertilizer interactions with other factors. Three of the four Milorganite-treated plots were included in the four highest TNC concentration subplots. Because the significant fertilizer main effect is illogical, we suspect that it is due to some other factor such as tree density.

Table 3—Comparison of mean total nonstructural carbohydrate concentration values for soil types, watering regimes, species, lift dates, and fertilizer treatments. Also included are the 95 percent confidence intervals based on a pooled variance

Treatment	*n*	TNC, mg/g	Confidence interval ±
Light soil	324	217.8	3.4
Heavy soil	313	231.5	3.5
High water	214	220.4	4.2
Intermediate water	216	219.3	4.2
Low water	207	234.2	4.3
Ponderosa pine	315	217.4	3.5
Lodgepole pine	322	231.5	3.4
Lift 1 (9/19)	107	155.3	4.4
Lift 2 (10/16)	103	187.8	4.4
Lift 3 (11/6)	107	225.0	4.4
Lift 4 (11/27)	107	243.9	4.4
Lift 5 (3/19)	107	234.6	4.4
Lift 6 (4/9)	106	299.9	4.4
Fertilizer 1	71	225.2	4.5
Fertilizer 2	71	230.4	4.5
Fertilizer 3	66	227.5	4.6
Fertilizer 4	71	221.2	4.5
Fertilizer 5	72	222.1	4.4
Fertilizer 6	72	227.2	4.4
Fertilizer 7	70	223.0	4.5
Fertilizer 8	72	222.5	4.4
Fertilizer 9	72	221.7	4.4

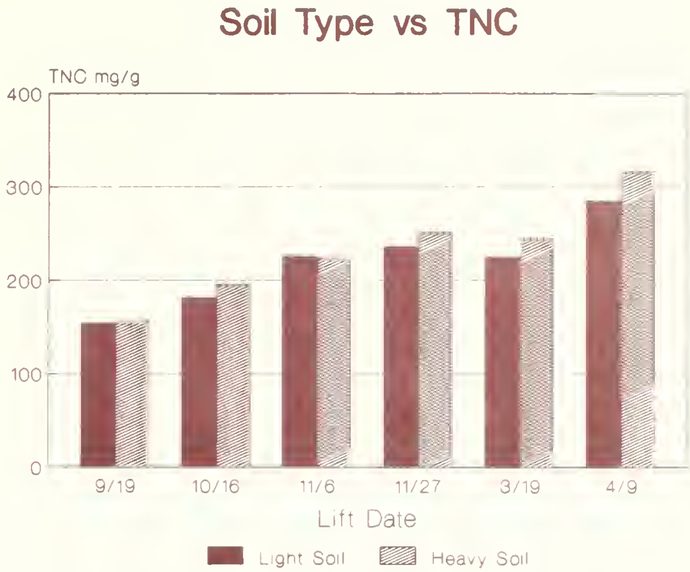


Figure 1—Total nonstructural carbohydrate concentration for seedlings grown in light and heavy soil plotted for each lift date.

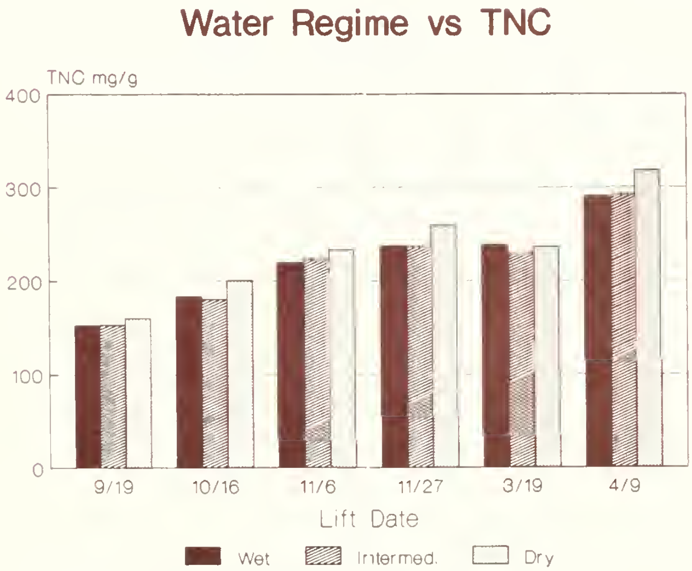


Figure 2—Total nonstructural carbohydrate concentration by water regimes plotted for each lift date.

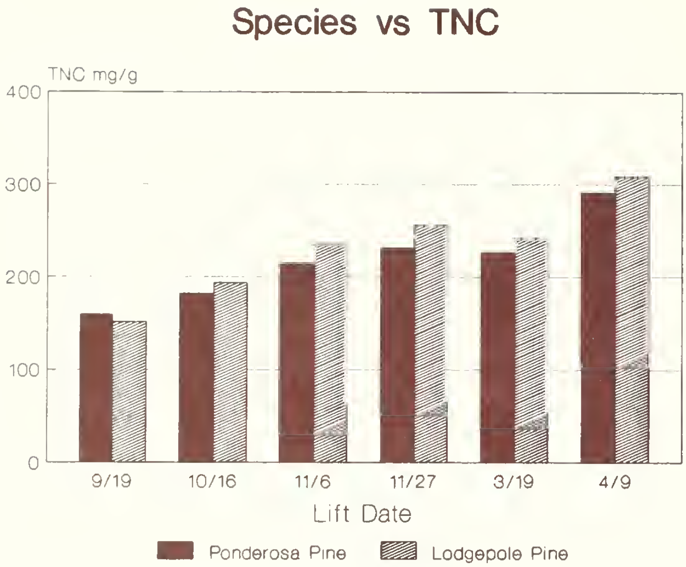


Figure 3—Comparison of total nonstructural carbohydrate concentration by lift date for ponderosa and lodgepole pine.

The sub-subplot comparisons of lift date and lift-date interactions with soil, water, and species all tested highly significant (table 2). Main effects of lift date, plotted on figure 4, show a sharp increase in TNC concentration until early winter, followed by a gradual decline over winter, then an increase in the spring. The strong main effect of lift date, which is exemplified by nearly twice the TNC concentration in lift dates April 8 to 10 compared to lift dates September 18 to 21, assured significant interactions with soil, water, and species.

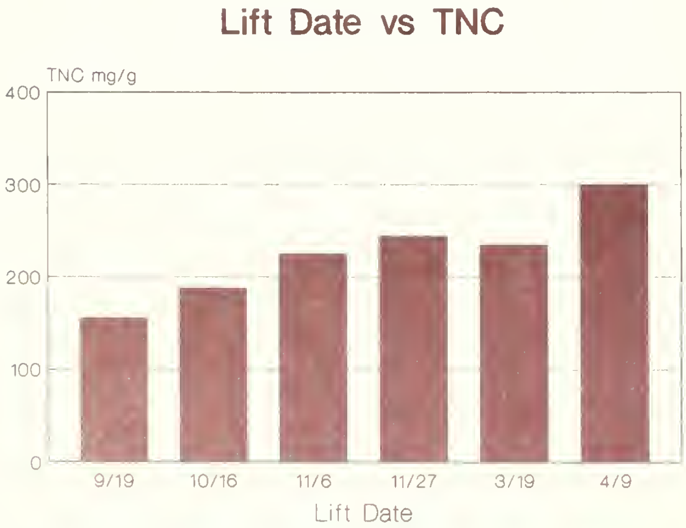


Figure 4—Total nonstructural carbohydrate concentration plotted as a function of lift date.

DISCUSSION

It is not clear why TNC concentrations in trees grown in heavy soil were higher than the concentrations in trees grown in light soil. The heavy soil plots required more frequent watering and more total water added to maintain the plant moisture stress levels. Plant moisture stress levels were often higher in the heavy soil at measurement time, and one might hypothesize that this reduced growth, resulting in smaller trees that reduced shading. This could result in more photosynthate produced per tree and higher photosynthate concentration per tree. However, there were no significant differences in tree size between heavy and light soil. The heavy soil might have held more nutrients. However, the lack of a logical fertilizer effect suggests that N and P were not limiting. It is possible that a higher exchangeable base status in the heavy soil contributed to the TNC difference, but this would require further study to verify.

Trees grown under the low water regime (high moisture stress) had a higher TNC concentration. Trees in the low water regime were significantly shorter, and this could have resulted in less shading and more photosynthate fixed per tree mass, or less respiration of photosynthate per unit time. Either explanation would be consistent with our findings. Iljin (1957) points out that extension growth commonly shows an early response to moisture stress, but photosynthesis continues for some time after growth stops.

Increases in TNC concentrations from lift dates September 18 to 21 to November 26 to 28 reflect low demand for photosynthate relative to production in the late fall, early winter period. This is consistent with Webb's (1977) findings for Douglas-fir seedlings. During the period between lift dates November 26 to 28 and March 18 to 20, when TNC concentration showed a slight decline, snow on the ground covered the seedlings. Following snowmelt, TNC again increased in concentration in the early spring. Photosynthate production probably exceeded demand during this period because of low temperatures. Wardlaw (1968) suggests that growth rates are affected more by low temperatures than photosynthesis, and this is demonstrated by an accumulation of soluble carbohydrate at low temperatures.

CONCLUSIONS

Do the significant differences in TNC concentration as a result of soil type, water regime, and lift date have any implications for nursery practices or planting success? The differences attributable to soil type or water regime were small (approximately 6 percent) and unlikely to affect survival and growth. However, there were large differences in TNC concentration (nearly a factor of two) from the first lift date to early winter or spring. Ronco (1973) found no correlation between survival and food reserves but did hypothesize that there must be some threshold level. This study did not intend to determine a threshold level below which carbohydrates are limiting. Followup studies are needed to determine if there is a threshold level and a field test or a greenhouse-simulated field test to show whether or not the levels found in this experiment make any difference. Not knowing the relationship between TNC and survival makes it difficult to predict the effect of lift date. However, late fall or spring lifting apparently will result in markedly higher TNC concentrations and may add a measure of safety.

ACKNOWLEDGMENTS

The authors are grateful to Michael Simpson for assistance in the field and for plant preparation, and to Sonia Caldwell and Tina Bell for laboratory assistance. Charles Graham provided valuable assistance in the statistical analysis.

REFERENCES

da Silveira, A. J.; Feitosa Teles, F. F.; Stull, J. W. 1978. A rapid technique for total nonstructural carbohydrate determination of plant tissue. Journal of Agriculture and Food Chemistry. 26: 770-772.

Iljin, W. S. 1957. Drought resistance in plants and physiological processes. Annual Review of Plant Physiology. 8: 257-274.

Krueger, K. W.; Trappe, J. M. 1967. Food reserves and seasonal growth of Douglas-fir seedlings. Forest Science. 13: 192-202.

McCracken, I. J. 1979. Changes in the carbohydrate concentration of pine seedlings after cool storage. New Zealand Journal of Forest Science. 9: 34-43.

Ritchie, G. A. 1982. Carbohydrate reserves and root growth potential in Douglas-fir seedlings before and after cold storage. Canadian Journal of Forest Research. 12: 905-912.

Ronco, F. 1973. Food reserves of Engelmann spruce planting stock. Forest Science. 19: 213-219.

Tiedemann, A. R.; McArthur, E. D.; Lopez, C. F. 1984. Carbohydrate and nitrogen concentrations in leaves of three shrub species following microwave, autoclave and air-drying treatments. Forest Science. 30: 113-116.

Van den Driessche, R. 1979. Respiration rate of cold-stored nursery stock. Canadian Journal of Forest Research. 9: 15-18.

Wardlaw, I. F. 1968. The control and pattern of movement of carbohydrate in plants. The Botanical Review. 34: 79-105.

Webb, W. L. 1977. Seasonal allocation of photoassimilated carbon in Douglas-fir seedlings. Plant Physiology. 60: 320-322.

August 1987
Intermountain Research Station
324 25th Street
Ogden, UT 84401

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-369

Estimating Singleleaf Pinyon and Utah Juniper Volumes for Several Utilization Standards

David C. Chojnacky
Caroline K. Wraith[1]

ABSTRACT

Volume ratio tables have been developed to convert singleleaf pinyon and Utah juniper volumes from a 1.5-inch minimum branch diameter to other utilization standards. Examples are presented on use of volume ratios for determining outside-bark and inside-bark cubic-foot volume for 1- to 6-inch minimum branch diameter standards.

KEYWORDS: *Pinus monophylla, Juniperus osteosperma*

Ratio equations were developed to estimate pinyon and juniper volume for several utilization standards. Results were presented in equation form in the Western Journal of Applied Forestry (Chojnacky 1987). Because many forestry practitioners prefer volume results in table form, the volume ratio equations are tabulated in this paper.

Tables 1 and 2 give volume ratios for determining outside-bark and inside-bark cubic-foot volume for minimum branch diameter **(mbd)** standards from 1 to 6 inches. The volume ratios are designed to reduce volume predictions from equations that yield outside-bark (ob) volume of all stem and branch wood larger than 1.5 inches (fig. 1).

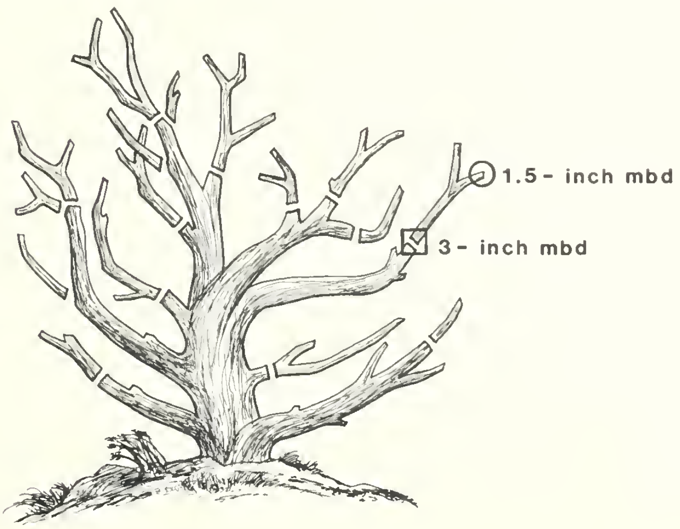


Figure 1—Comparison between 1.5-inch and 3-inch minimum branch diameter (mbd).

---

[1] Research forester and forestry technician at Intermountain Research Station's Forestry Sciences Laboratory, Ogden, UT.

PINYON TABLE

Table 1—Pinyon volume ratios for determining outside-bark and inside-bark cubic-foot volume to different utilization standards

		Minimum branch diameter (inches)									
DSH	**Basal stems**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**
Inches		*Outside bark*					*Inside bark*				
4	Single	0.87	0.73				0.74	0.60	0.49		
	Multiple	.77	.53				.64	.45	.30		
6	Single	.88	.75	0.65	0.56		.76	.64	.54	0.46	0.38
	Multiple	.80	.61	.46	.33		.70	.54	.40	.29	.19
8	Single	.89	.77	.67	.59	0.51	.78	.67	.58	.50	.43
	Multiple	.83	.66	.52	.41	.31	.73	.59	.47	.37	.27
10	Single	.89	.78	.69	.61	.53	.79	.69	.60	.53	.46
	Multiple	.84	.69	.57	.47	.38	.75	.62	.51	.42	.34
12	Single	.90	.79	.70	.62	.55	.80	.70	.62	.55	.48
	Multiple	.86	.71	.60	.51	.43	.77	.65	.55	.46	.38
14	Single	.90	.79	.71	.63	.56	.81	.71	.63	.57	.50
	Multiple	.87	.73	.63	.54	.46	.78	.67	.58	.49	.42
16	Single	.90	.80	.71	.64	.58	.82	.72	.65	.58	.52
	Multiple	.87	.75	.65	.57	.49	.79	.69	.60	.52	.45
18	Single	.91	.80	.72	.65	.59	.82	.73	.66	.59	.54
	Multiple	.88	.76	.67	.59	.52	.80	.70	.62	.54	.47
20	Single	.91	.81	.73	.66	.60	.83	.74	.67	.60	.55
	Multiple	.88	.77	.68	.61	.54	.81	.71	.63	.56	.50
22	Single	.91	.81	.73	.67	.60	.83	.74	.67	.61	.56
	Multiple	.89	.78	.70	.62	.56	.82	.72	.65	.58	.51
24	Single	.91	.81	.74	.67	.61	.83	.75	.68	.62	.57
	Multiple	.89	.79	.71	.64	.58	.83	.73	.66	.59	.53

$$\hat{V}R_{ob} = \begin{cases} 1 - [0.27612(\text{mbd} - 1.5)^{0.67360} / \text{DSH}^{0.21114}] & \text{for single-stem trees} \\ 1 - [0.66949(\text{mbd} - 1.5)^{0.62895} / \text{DSH}^{0.44205}] & \text{for multiple-stem trees} \end{cases}$$

$$\hat{V}R_{ib} = \begin{cases} 1 - [0.37567(\text{mbd})^{0.59369} / \text{DSH}^{0.25692}] & \text{for single-stem trees} \\ 1 - [0.61912(\text{mbd})^{0.61412} / \text{DSH}^{0.39859}] & \text{for multiple-stem trees} \end{cases}$$

where

VR_{ob} = outside bark volume ratio
VR_{ib} = inside bark volume ratio
mbd = minimum branch diameter (inches)
DSH = basal diameter at 6-inch stump height (inches).

JUNIPER TABLE

Table 2—Juniper volume ratios for determining outside-bark and inside-bark cubic-foot volume to different utilization standards

DSH	Basal stems	Minimum branch diameter (inches)									
		2	3	4	5	6	1	2	3	4	5
Inches		*Outside bark*					*Inside bark*				
4	Single	0.83	0.66				0.68	0.53	0.42		
	Multiple	.71	.44				.59	.40	.25		
6	Single	.86	.71	0.59	0.49		.72	.58	.48	0.39	0.31
	Multiple	.76	.54	.37	.24		.64	.47	.34	.22	.12
8	Single	.87	.74	.64	.55	0.46	.74	.61	.52	.43	.3
	Multiple	.79	.59	.45	.33	.22	.67	.51	.39	.29	.19
10	Single	.88	.76	.67	.58	.51	.75	.64	.55	.47	.40
	Multiple	.81	.63	.50	.40	.30	.69	.55	.43	.33	.25
12	Single	.89	.78	.69	.61	.54	.76	.65	.57	.49	.43
	Multiple	.82	.66	.54	.44	.35	.71	.57	.46	.37	.29
14	Single	.90	.79	.71	.63	.57	.77	.67	.59	.51	.45
	Multiple	.84	.69	.58	.48	.40	.72	.59	.49	.40	.32
16	Single	.90	.80	.72	.65	.59	.78	.68	.60	.53	.47
	Multiple	.85	.71	.60	.51	.43	.73	.61	.51	.42	.35
18	Single	.91	.81	.73	.67	.61	.79	.69	.61	.55	.49
	Multiple	.85	.72	.62	.54	.46	.74	.62	.53	.44	.37
20	Single	.91	.82	.74	.68	.62	.80	.70	.62	.56	.50
	Multiple	.86	.73	.64	.56	.49	.75	.63	.54	.46	.39
22	Single	.91	.82	.75	.69	.64	.80	.71	.63	.57	.51
	Multiple	.87	.75	.65	.58	.51	.76	.64	.55	.48	.41
24	Single	.92	.83	.76	.70	.65	.81	.71	.64	.58	.52
	Multiple	.87	.76	.67	.60	.53	.76	.65	.57	.49	.42

$$\hat{VR}_{ob} = \begin{cases} 1 - [0.44761\,(\text{mbd} - 1.5)^{0.65698} / \text{DSH}^{0.38835}] & \text{for single-stem trees} \\ 1 - [0.82565\,(\text{mbd} - 1.5)^{0.59404} / \text{DSH}^{0.45831}] & \text{for multiple-stem trees} \end{cases}$$

$$\hat{VR}_{ib} = \begin{cases} 1 - [0.46178\,(\text{mbd})^{0.55473} / \text{DSH}^{0.27152}] & \text{for single-stem trees} \\ 1 - [0.62671\,(\text{mbd})^{0.55423} / \text{DSH}^{0.30675}] & \text{for multiple-stem trees} \end{cases}$$

where

VR_{ob} = outside bark volume ratio

VR_{ib} = inside bark volume ratio

mbd = minimum branch diameter (inches)

DSH = basal diameter at 6-inch stump height (inches).

Multiplying predicted volume times a volume ratio for a specified **mbd** yields volume to the specified **mbd**. This technique can be applied to the pinyon and juniper volume equations given by Chojnacky (1985) for the central Rocky Mountain States.

METHODS

Singleleaf pinyon (*Pinus monophylla* Torr. & Frém.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) trees were felled at 61 locations throughout the Great Basin on lands administered by the U.S. Department of the Interior, Bureau of Land Management (fig. 2).

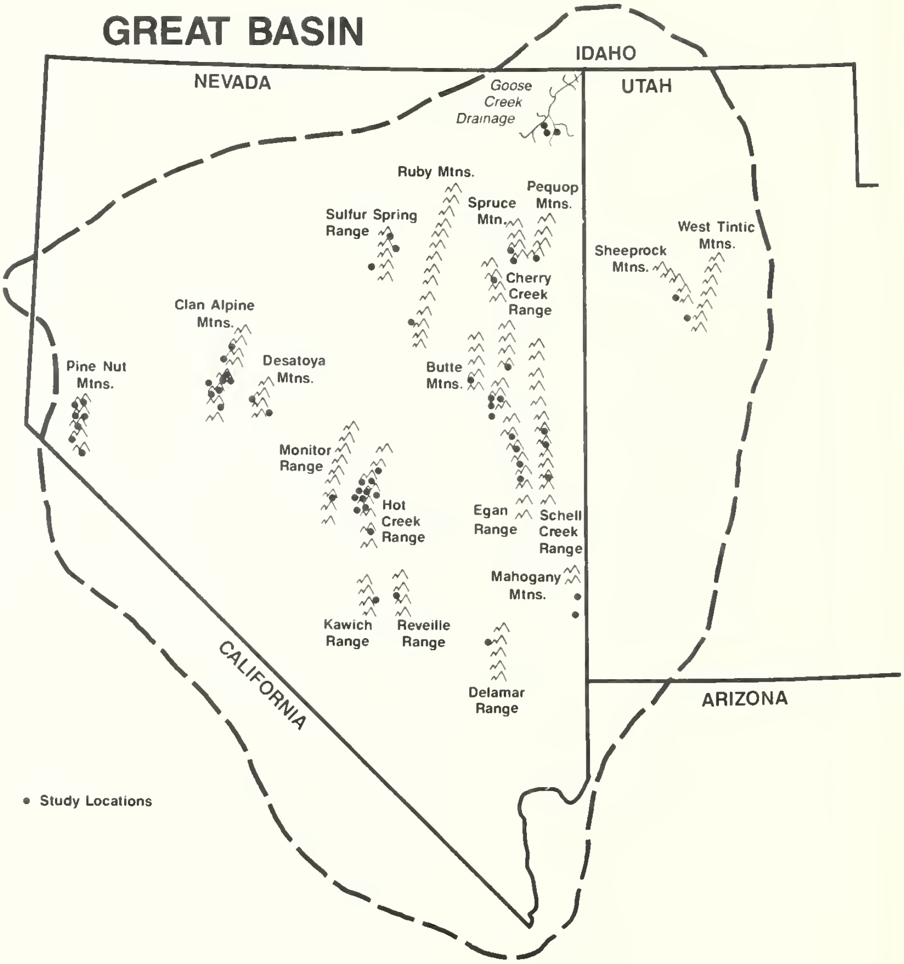


Figure 2—Map of 61 study locations.

Sample trees (having at least one basal stem ⩾ 3 inches) were measured for basal diameter at ground line near the root collar (DRC) and above ground line at 6-inch stump height (DSH). For multiple-stem trees that forked at or below either measurement point, an equivalent diameter (ED) was computed:

$$ED = \sqrt{\sum_{i=1}^{n} D_i^2}$$

where

D_i = diameter of each stem larger than 1.5 inches

n = number of stems larger than 1.5 inches.

Wood volume was determined by using Newton's log formula (Husch and others 1982, p. 101) to compute cubic-foot volume for each tree cut into segments. Volumes for **mbd** ranging from 1 to 6 inches were computed for each tree. Nonlinear regression was used to model the data into volume ratio equations.

DIAMETER CONVERSIONS

Because previous pinyon and juniper inventories measured basal diameter at DRC, diameter conversion equations were developed to convert DRC to DSH for both pinyon and juniper (Chojnacky 1987):

Pinyon

$$\mathrm{DSH} = -0.03 + (0.9826 \cdot \mathrm{DRC}) - (0.20 \cdot \mathrm{STEM}) \qquad (1)$$

Juniper

$$\mathrm{DSH} = -0.77 + (0.9603 \cdot \mathrm{DRC}) + (0.22 \cdot \mathrm{STEM}) \qquad (2)$$

where

DRC = diameter at ground line (inches)
DSH = diameter at 6-inch stump height (inches)
STEM = 1 if single-stem tree, 0 otherwise.

These equations can therefore be used to apply volume ratio results to trees measured at DRC, as well as to trees measured at DSH.

APPLICATION OF VOLUME EQUATIONS

Examples of volume ratio application are illustrated for a single-stem 14-foot pinyon with a 15.5-inch DRC, and a multiple-stem 12-foot juniper with a 13.3-inch DRC. Volume equations for the examples are taken from Chojnacky (1985). The diameter conversion equation for each species is illustrated in step 1.

A: **Single-stem pinyon** (14 feet tall with a 15.5-inch DRC):

Step 1. **Diameter conversion** (only needed if appropriate diameter missing)
If DRC = 15.5
Then DSH = 15.0 (from eq. 1)

Step 2. **Volume ratio outside bark for 3-inch mbd (ob)**
If DSH = 15.0 and mbd = 3
Then $\mathrm{VR}_{ob} = 0.80$ (from table 1)

Step 3. **Volume outside bark for 1.5-inch mbd (ob)**
If DRC = 15.5 and height = 14
Then $V = 8.76\ \mathrm{ft}^3$ (from table 13 in Chojnacky 1985)

Step 4. **Volume outside bark for 3-inch mbd (ob)**
Therefore, $(\mathrm{VR}_{ob})(V) = (0.80)(8.76) = 7.01\ \mathrm{ft}^3$

B: **Multiple-stem juniper** (12 feet tall with a 13.3-inch DRC):

Step 1. **Diameter conversion**
If DRC = 13.3
Then DSH = 12.0 (from eq. 2)

Step 2. **Volume inside bark for 3-inch mbd (ib)**
If DSH = 12.0 and mbd = 3
Then $\mathrm{VR}_{ib} = 0.46$ (from table 2)

Step 3. **Volume outside bark for 1.5-inch mbd (ob)**
If DRC = 13.3 and height = 12
Then $V = 3.98\ \mathrm{ft}^3$ (from table 6 in Chojnacky 1985)

Step 4. **Volume inside bark for 3-inch mbd (ib)**
Therefore, $(\mathrm{VR}_{ib})(V) = (0.46)(3.98) = 1.83\ \mathrm{ft}^3$

REFERENCES

Chojnacky, D. C. 1985. Pinyon-juniper volume equations for the central Rocky Mountain States. Res. Pap. INT-339. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 27 p.

Chojnacky, D. C. 1987. Estimating singleleaf pinyon and Utah juniper volumes for several utilization standards. Western Journal of Applied Forestry. 2(2): 51-55.

Husch, B.; Miller, C. I.; Beers, T. W. 1982. Forest mensuration. 3d ed. New York: John Wiley & Sons. 402 p.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

August 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-370

Comparative Vegetational Recovery on Firelines Cleared with Explosives and with Handtools

Nonan V. Noste
Richard J. Barney[1]

ABSTRACT

Vegetational recovery was compared on firelines constructed in three ground fuel cover types, using conventional handtools and two types of fireline explosives. Measurement of ground coverage of shrub and herb species before and after disturbance indicated similar vegetational recovery on blasted and hand-dug fireline.

KEYWORDS: wildland fire, fire control, vegetation, environmental impact

Although the chainsaw, shovel, and pulaski remain basic tools for making firelines, special explosive packages have become a promising alternative. The advantages of blasting fireline in terms of cost, timeliness, and general effectiveness have been established (Barney 1984). But fire managers also are concerned about the environmental impacts of blasting.

Blasting evokes images of violent disturbance to the site. Examination of newly blasted fireline suggested that blasted fireline does not disturb the site more than line dug with handtools. But the question of comparative vegetational recovery remained unanswered. This report presents initial results of a study to investigate early vegetational recovery following disturbance.

Objectives of the study were to: (1) determine amount and kind of vegetation before and after constructing fireline with handtools and with explosives; and (2) compare vegetation recovery on the disturbed areas.

METHODS

The fireline study was done in conjunction with firefighter training on the Ninemile Ranger District, Lolo National Forest, MT. Firelines were dug with handtools and blasted with two explosives used by the Forest Service to blast firelines: a dry chemical charge (Fireline Cord, manufactured by Ensign-Bickford[2]) and water-gel (Iremite 60, manufactured by IRECO) (Barney 1984). Vegetation was evaluated prior to fireline construction in 1983, and afterwards in 1984. Because vegetation succession is so dependent upon initial vegetation response, long-term monitoring was not considered necessary to accomplish the study objectives.

The three fireline construction methods were tested in each of three fuel conditions. Firelines were generally constructed parallel to each other at each site. Replications were not made in this preliminary study. An attempt was made, however, to construct each line within fuel type (Barney 1984) in similar conditions. The light, medium, and heavy fuel types represent fuel models 2, 8, and 10, respectively (Anderson 1982). Fuels (Stockstad and others 1986) graded from light to medium in a Douglas-fir (*Pseudotsuga menziesii*) habitat type (Pfister and others 1977) to heavy in a grand fir (*Abies grandis*) habitat type.

Nine vegetation transects were established along 100-ft long segments of fireline in each of the three types of fireline in each of the three fuel conditions. Twenty plots (½- by ½-m) for sampling vegetation were established at 5-ft intervals along the firelines.

---

[1] Research forester located at Intermountain Fire Sciences Laboratory, and fire management specialist, Systems for Environmental Management, Missoula, MT.

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Percentage of cover by plant species was used as a measure of plant response to disturbance. Percentage of cover is the portion of the surface covered by leaves and plant parts projected vertically to the ground. Percentage of cover by species was estimated by the following cover classes (Daubenmire 1959):

Class	Percent cover
1	0-5
2	5-25
3	26-50
4	51-75
5	76-95
6	96-100

When building fireline, the greater the disturbance, the more plants killed, hence less sprouting and more opportunity for plants to establish from seed (Arno and others 1985). Plants of each species were excavated and examined between plots along the length of each fireline section and were classified according to reproductive mode (seedling vs. sprout) into the following three classes:

Reproductive mode	Percent seedlings
Mostly vegetative	0-33
Mixed mode	34-66
Mostly seed	67-100

RESULTS

Degree of disturbance can be judged by comparing both pretreatment (1983) and posttreatment (1984) plant cover in each fire control method and fuel condition (table 1). The general pattern is a large reduction in percentage of cover for all treatments in all fuel conditions. This result can be expected because the objective of building fireline is to remove live and dead vegetation and to expose mineral soil. In the medium fuel condition, however, total cover was reduced 7 percent (from 35 to 28) on the hand-dug line but increased 38 percent (22 to 60) on the Ensign-Bickford line. This aberration may be the result of the small sample, and may not be characteristic of the treatment. There was no difference in vegetational recovery on the firelines constructed with explosives as compared to the hand-dug line.

Table 1—Vegetational cover (percent) before (1983) and after (1984) constructing fireline with handtools and explosives (water-gel, dry cord) in three fuel conditions

	Handtools		Water-gel		Dry cord	
Fuel condition	1983	1984	1983	1984	1983	1984
Light fuels						
Grass	8	7	37	20	15	11
Forbs	14	12	14	26	24	8
Shrubs	28	12	33	3	11	5
Total	50	31	84	49	50	24
Medium fuels						
Grass	5	2	12	9	3	4
Forbs	15	14	20	24	10	27
Shrubs	15	12	33	16	9	29
Total	35	28	65	49	22	60
Heavy fuels						
Grass	9	12	25	9	19	7
Forbs	45	22	56	20	31	17
Shrubs	28	11	12	4	36	18
Total	82	45	93	33	86	42

Table 2—Average number and percentage of species by reproductive mode on fireline constructed with handtools and explosives

	Handtools		Explosives	
Reproductive mode	Species	Percent	Species	Percen
Vegetative (<33 percent seedlings)	25	31	31	35
Seed (>66 percent seedlings)	42	52	42	48
Mixed mode (33-66 percent seedlings)	14	17	15	17

Degree of disturbance expressed as a percentage of plant seedlings was computed as the sum of the species in each reproductive class added over the three fuel conditions within the fire control method (table 2). A species could occur in each fuel condition, but may be classified as reproducing differently. The proportion of species reproducing from seed and sprouting is very similar on the hand-dug firelines and blasted firelines, indicating similar degree of disturbance.

CONCLUSIONS

In general, linear explosives are at least no more damaging to vegetation than hand-dug line. More detailed study with more samples and a broader look at habitat types may show a more definitive relationship. Also, other measurements and parameters may be more important in quantifying disturbance between different fireline construction methods than percentage of plant cover. For example, biomass measurement or frequency of occurrence may be useful.

The fire manager need not fear inordinate vegetational disturbance or lack of recovery from use of fireline explosives. Based on the limited work we reported here, vegetational recovery is similar on fireline made with handtools and line blasted with explosives.

REFERENCES

Anderson, Hal E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Arno, Stephen F.; Simmerman, Dennis G.; Keane, Robert E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

arney, Richard J. 1984. Characteristics of fireline blasted with linear explosives: initial test results. Res. Note INT-345. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

aubenmire, R. F. 1959. Canopy coverage method of vegetation analysis. Northwest Science. 33: 43-64.

fister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 173 p.

tockstad, Dwight S.; Kurth, Troy W.; Barney, Richard J. 1986. Fireline explosives - a second look. Fire Management Notes. 47(1): 18-21.

August 1987
Intermountain Research Station
324 25th Street
Ogden, UT 84401

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

☆ U.S. GOVERNMENT PRINTING OFFICE:1987-773-039/61018

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-371

Armillaria in the Northern Rockies: Pathogenicity and Host Susceptibility on Pristine and Disturbed Sites

G. I. McDonald
N. E. Martin
A. E. Harvey

August 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Armillaria in the Northern Rockies: Pathogenicity and Host Susceptibility on Pristine and Disturbed Sites

G. I. McDonald
N. E. Martin
A. E. Harvey[1]

ABSTRACT

Over all plots (disturbed and pristine), incidence of pathogenic Armillaria *showed a strong tendency to decrease as habitat type productivity increased. This trend gave rise to a clear separation of plots by climax series. The relatively less productive subalpine fir and Douglas-fir series exhibited high incidence of root disease and the relatively more productive grand fir, western redcedar, and western hemlock series significantly less. Within these productivity groups, other patterns emerged. Disturbance appeared to be related to a dramatic increase in incidence of pathogenicity, but not occurrence, within the high-productivity grouping of communities. Also, the ability of disturbance to elicit pathogenicity seemed to decline as site productivity increased. Conversely, the pristine plots within the low-productivity series exhibited high incidence of the pathogen in a pathogenic state. This condition seemed to be related to a community structure characteristic of transition between cold-dry to cool-moist and warm-dry to warm-moist. Predicting risk of* Armillaria-*caused mortality, occurrence of pathogenic species and clones of* Armillaria, *a possible role for host stress in expression of pathogenicity by* Armillaria, *and risk rating of host species are discussed.*

KEYWORDS: habitat types, host stress, root rot management, root rot risk, risk rating, disease hazard

Armillaria commonly occurs as rootlike rhizomorphs growing on plant debris or epiphytically attached to root systems of dead, diseased, or healthy host plants (Garrett 1960; Kile 1980; Leach 1939; Raabe and Trujillo 1963; Redfern 1973). Isolates obtained from such rhizomorphs, as well as isolates obtained from mycelial fans, decayed wood, and sporophores, can belong to clones or species whose apparent pathogenicity varies from very high to obligately saprophytic (Kile 1983; Rishbeth 1982; Wargo and Shaw 1985).

Severity of this *Armillaria*-caused root disease tends to increase as management intensifies. Partial cutting (Filip 1977; Filip and Goheen 1982; Redfern 1978), excessive grazing (Bega 1979), and fire control (Shaw and others 1976) all appear to increase activity of *Armillaria*. In Queensland, Australia, *Armillaria* was found in nearly all stumps after clearcutting of a first-rotation introduced pine forest (Anon. 1982). Chemical and mechanical killing of hardwood brush or timber is linked to increased activity (Pronos and Patton 1977; Swift 1972). Conifer plantations replacing clearcut conifer or hardwood forests have experienced significant *Armillaria*-related mortality (Redfern 1978; Shaw and Roth 1978). Even method and quality of planting (Rykowski 1981) can influence damage caused by this organism (Singh and Richardson 1973). There are several interactions between *Armillaria* root rot and the actions of insects and other diseases (Dunbar and Stephens 1975; Madziara-Borusiewicz and Strzelecka 1977; Singh and Raske 1983; Wargo 1977, 1981). Slash disposal methods may also affect *Armillaria*; woody debris incorporated into the soil can be a significant food base increasing the inoculum potential and thereby becoming a source of new infections (Garrett 1960; Raabe and Trujillo 1963).

Many researchers have reported ubiquitous distribution and host ranges of *Armillaria* spp. (Ehrlich 1939; Hobbs and Partridge 1979; Hubert 1950; Swift 1972). The primary objective of these studies, however, was to determine degree of damage to affected hosts rather than extent of occurrence of the fungus. Other examples are Carey and others (1984), Williams and Marsden (1982), and James and others (1984), wherein sample points were selected by first locating symptomatic trees or root disease centers. We recently demonstrated that *Armillaria* distribution, as determined by randomly located plots, is related to habitat type (McDonald and others in press).

No information is presently available regarding probability of encountering, from randomly selected forest locations, the genus *Armillaria* in pathogenic mode on any host. Such information is important because probability of occurrence (at quantitative level, for instance, proportion of 0.04-ha plots) of pathogenic *Armillaria* in relation to stand attributes can serve to classify forest lands for options and risk to host species given specific management actions.

---

[1] Principal plant pathologist, plant pathologist, and principal plant pathologist, respectively, located at Intermountain Station's Forestry Sciences Laboratory, Moscow, ID.

We began a study of population-level genetic and ecologic interactions between *Armillaria* and its conifer and hardwood hosts in 1983. One objective was to predict the probability of *Armillaria*-caused damage to hosts by geographic location, host species, and stand management history. A major concern addressed by this study was the association of pathogenic *Armillaria* with habitat type and management history, as judged by signs of the fungus and disease symptoms found on randomly located plots.

This paper reports on the occurrence of pathogenic *Armillaria* by host species, plot vegetation—community type (habitat type), and the effect of human disturbance on culturally verified rhizomorph and fan collections of *Armillaria*.

MATERIALS AND METHODS

The root systems of at least one living and apparently healthy representative of all major hardwood and conifer species on each plot were inspected for fans, decayed wood, and (epiphytic) rhizomorphs. The inspection consisted of exposing the root collar and major roots to a depth of about 0.3 m and a lateral spread of 0.5 to 1 m, then looking for decay and fans by chopping away the bark. This inspection required 1 to 3 hours per plot. Evidence of man's activity, such as road building or previous cutting, within 75 m of a plot was recorded. Finally, any unhealthy or recently dead trees (from seedlings to mature) were inspected for the cause of their condition. Trees with fans and root resinosis, fans and green needles, or fans and red needles were recorded as *Armillaria*-killed or damaged, and isolates of fans were taken.

Pathogenic *Armillaria* was said to have been encountered if a dead tree exhibited enough resinosis to soak the soil in the area of the root crown, or if the cambium showed a wound reaction common in living trees at the site of *Armillaria* fan attachment. Fans alone on a dead tree were not considered adequate evidence that *Armillaria* had been instrumental in death of a tree. Fans alone were taken as positive evidence of pathogenicity if the tree was healthy in appearance, declining, or recently dead (red-brown needles). Tree size was not considered. Pathogenic encounter was recorded if signs and symptoms, or both, were found on plants within 25 m of the 400-m^2 plot.

All plots were classified by habitat type according to appropriate dichotomus keys based on lists of indicator plants and by study of plot photos and plant lists by an experienced ecologist (Neiman 1984). Habitat type of the few plots that occurred on recent or regenerated clearcuts was determined by inspection of adjacent stands. Plots were pooled by climax series for analyses. The expected site index for each series was obtained from series descriptions (Cooper and others in press; Steele and others 1981; Pfister and others 1977). Plots were further classified as nondisturbed and human-disturbed. The proportion of each class within each series and of some individual habitat types was calculated. For those plots supporting saprophytic or pathogenic *Armillaria*, or both, on a specific host species, we computed the proportion of that host species that was damaged.

RESULTS

Distribution of Pathogenic *Armillaria*

When plots supporting pathogenic *Armillaria* were classified by climax indicator species, the heterogeneity chi-square was significant at 8 percent (table 1). Second, the likelihood of encountering pathogenicity appeared to decrease with increasing productivity (site index) among the series (table 1). The relationship between community stability, community productivity, disturbance, and pathogenicity was investigated (table 2). The comparison for occurrence of pathogenicity on disturbed and undisturbed low-productivity sites yielded a nonsignificant heterogeneity chi-square (table 2). But disturbed high-productivity plots compared to undisturbed high-productivity plots showed a heterogeneity chi-square significant at 0.005 (table 2). Undisturbed-low and undisturbed-high were also significantly different (table 2). Thus, disturbed high-productivity plots had more pathogenicity than undisturbed high-productivity plots. Undisturbed low-productivity plots showed more pathogenicity than undisturbed high-productivity plots, and undisturbed low-productivity plots were not different from disturbed high-productivity plots.

Rankings of Conifer Species

The proportion of pathogenic *Armillaria* on particular hosts was computed for the 10 most common host species in each series (table 3). The proportion was calculated only from plots where both *Armillaria* and the host were present. The species sorted into three groups: (1) Western larc (*Larix occidentalis*), western hemlock (*Tsuga heterophylla*), and western white pine (*Pinus monticola*) that did not support pathogenic *Armillaria*, (2) ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and western redcedar (*Thuja plicata*) that exhibited moderate levels of pathogenicity, and (3) Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) that exhibited a high incidence of pathogenic encounter, particularly when they were climax.

Table 1—Incidence of pathogenic *Armillaria* in habitat types known to support *Armillaria*. Plots are classified by climax vegetation and listed in order of increasing productivity site index

Climax species	Site index	Number of plots	Proportion of pathogenic *Armillaria*
Subalpine fir	16.15	15	0.53
Douglas-fir	16.46	[1]6	.67
Grand fir	19.81	42	.309
Western redcedar	21.95	10	.20
Western hemlock	22.56	15	.13

χ^2 = 8.32, d.f. = 4, prob. of larger χ^2 = 0.08.

[1] Includes the single ponderosa pine series plot.

Table 2—Incidence of pathogenic *Armillaria* on 78 randomly selected 0.04-ha plots having *Armillaria* in some form. Plots were classified by plot productivity (high and low) (see table 1) and man-caused disturbance[1]

Disturbance-productivity combination	Number of plots	Proportion with *Armillaria*	[2]χ^2	$P \leqslant \chi$
Disturbed-low	4	0.25		
Undisturbed-low	17	.65	0.78	0.4
Disturbed-high	17	.59		
Undisturbed-high	40	.18	7.86	.005
Disturbed-low	4	.25		
Disturbed-high	17	.59	.44	.6
Undisturbed-low	17	.65		
Undisturbed-high	40	.18	10.22	.005
Undisturbed-low	17	.65		
Disturbed-high	17	.59	0	1.0
Disturbed-low	4	.25		
Undisturbed-high	40	.18	1.24	.3

[1] Undisturbed = pristine plots 75 or more meters from human disturbance. Disturbed = in or within 75 meters of thinning, clearcut, or roadside.

[2] Chi square calculated according to Snedecor (1956) for 2 by 2 contingency table with correction for continuity.

DISCUSSION

Our conclusions about pathogenicity are: (1) incidence of pathogenic *Armillaria* decreases as primary productivity among series increases; (2) incidence of pathogenic *Armillaria* decreases as productivity of habitat types within the ABGR, THPL, and TSHE series (see definitions in table 3) increases; (3) incidence of pathogenicity was high (59 percent) on disturbed plots in the ABGR, THPL, and TSHE series; (4) incidence of pathogenicity was low (18 percent) on undisturbed plots in the ABGR, THPL, and TSHE series; (5) incidence of pathogenicity was high (65 percent) on undisturbed plots in the PSME and ABLA series; and (6) incidence of pathogenicity was low (25 percent) on disturbed plots in the PSME and ABLA series. Because the undisturbed plots represent the natural situation, we conclude that human activities have increased the incidence of pathogenicity threefold within the ABGR, THPL, and TSHE series.

A conclusion about human activities within the PSME and ABLA series is not possible because of the small number of plots in the disturbed class. Nevertheless, *Armillaria* clearly is exhibiting considerable pathogenic behavior on some habitat types within these series even in the absence of human activity. These plots appear to represent transitional zones between moist-cool to moist-warm sites on the one hand, and either cold-dry or warm-dry on the other. They probably occurred in our sample as undisturbed because they tend to be low-quality sites and are unattractive harvesting targets.

New evidence presented by Morrison and others (1985) links *A. ostoyae* to damage on conifers throughout southern British Columbia. These authors point out that knowledge of geographic range of the pathogen species does not explain damage differences between coastal and interior forests. Their explanation is variation in pathogenicity between coastal and interior forms of a single species—*Armillaria ostoyae.* If we can accept that pathogenic situations observed in our study were caused only by *A. ostoyae*, then our results suggest variation in pathogenicity of this species is linked to site productivity, host adaptation, or stress.

The hypothesis that is preferred by the authors to explain all relevant observations about *Armillaria* behavior in western North America is that the fungus, perhaps *A. ostoyae*, acts as a facultative pathogen that causes the most damage on stressed conifers. This is the proposed mode of action for *Armillaria* (species unknown) in forests

Table 3—Rankings of conifer species susceptibility to *Armillaria* within plant community climax series on plots in 15 Northern Rocky Mountain National Forests

Host species	Series					
	ABLA	PSME	ABGR	THPL	TSHE	All
PIPO[1]	— —	1/3 = 33	0/9 = 0	— —	— —	1/2 = 8
PICO	[2]1/8 = 13	0/5 = 0	2/14 = 14	0/2 = 0	0/4 = 0	3/33 = 9
PIMO	— —	— —	0/8 = 0	0/2 = 0	0/6 = 0	0/16 = 0
PSME	2/8 = 25	36 = 50	6/29 = 21	1/8 = 13	1/8 = 13	13/59 = 22
LAOC	0/5 = 0	0/5 = 0	0/22 = 0	0/4 = 0	0/10 = 0	0/46 = 0
TSHE	— —	— —	— —	— —	0/14 = 0	0/14 = 0
THPL	— —	— —	— —	1/10 = 10	0/11 = 0	1/21 = 5
PIEN	3/14 = 21	0/2 = 0	4/17 = 24	0/2 = 0	1/5 = 20	8/40 = 20
ABGR	— —	— —	7/31 = 23	2/9 = 22	0/9 = 0	9/49 = 18
ABLA	6/15 = 40	— —	0/7 = 0	0/2 = 0	1/3 = 33	7/27 = 26
All	12/50 = 24	4/21 = 19	19/137 = 14	4/39 = 10	2/70 = 3	

[1] PIPO = *Pinus ponderosa*, PICO = *Pinus contorta*, PIMO = *Pinus monticola*, PSME = *Pseudotsuga menziesii*, LACO = *Larix occidentalis*, TSHE = *Tsuga heterophylla*, THPL = *Thuja plicata*, PIEN = *Picea engelmannii*, ABGR = *Abies grandis*, ABLA = *Abies lasiocarpa*.

[2] Number of pathogenic occurrences (by plot) on specified host/number of occurrences within series when both species and *Armillaria* were present.

of the Eastern United States (Wargo 1979, 1984; Wargo and Shaw 1985).

Our hypothesis would explain the following: (1) The habitat types where *Armillaria* appears to cause high damage to undisturbed subalpine fir and Douglas-fir are transitional between relatively stable cold-dry and cool-moist regions and between hot-dry and warm-moist regions. Thus, these two damaged species may represent maladapted transitional populations, even though they are growing in their "natural environment." (2) Within the relatively more stable environments represented by the ABGR, THPL, and TSHE series, a slightly different mechanism may work. Here the physiologic traits of most species have the acclimative tolerances to withstand natural stresses, but these tolerances are exceeded for grand fir, Douglas-fir, lodgepole pine, Engelmann spruce, and possibly western redcedar and ponderosa pine when human-caused perturbations result in severe site modification as discussed by Likens (1985). In accordance with this hypothesis, two of the tolerant species (PIMO, LAOC) are known to possess shallow adaptive clines (Rehfeldt 1982; Rehfeldt and others 1984). Also, in any stressful situation, additions of anthropogenic inputs such as lead (Smith 1984) could tip the balance in favor of a pest. As productivity of the site increases, the impact of the perturbation lessens. When a highly productive state, as represented by the most productive sites in northern Idaho and like sites west of the Cascade crest, is reached, adaptive tolerances are not exceeded.

CONCLUSIONS

Pathogenic behavior, within the ecological range of the fungus, depends on specific combinations of habitat type and stand development history. Hypothesized patterns of occurrence must be validated before being put to general use in predicting risk to *Armillaria*. Validation is important because risk prediction has potential for extension to other parts of the Western United States, both for *Armillaria* and for other endemic diseases of forest trees. This approach should be highly effective for root pathogens of woody plants. The occurrence and function of many of these fungi are likely tied to long-term soil and climatic conditions, just as is the case with occurrence of the indicator plants.

Armillaria species and clones are known to encompass nonpathogenic saprophytes, secondary pathogens, amd primary pathogens (Morrison 1982; Rishbeth 1982; Shaw 1977). Hypotheses that could explain such varied behavior are site-specific stressing of hosts or varying geographic distribution patterns of pathogenic and nonpathogenic forms. A most important avenue of future research is the determination of which hypotheses or combinations give the best explanation. The results presented in this paper are based solely on host responses and point to existence of an *Armillaria* (perhaps *A. ostoyae*) that functions as an ecosystem scavenger or secondary pathogen which works mostly on stressed hosts. Nevertheless, our results do not rule out the existence of an *Armillaria* that functions as a primary pathogen with geographic clines varying in pathogenicity (Morrison and others 1985). To answer this question will require much data about the geographic and host range of individual *Armillaria* clones.

Regardless of ultimate explanations, results presented in this paper indicate that forest managers will need to know habitat type and management history of Northern Rocky Mountain stands to make informed decisions relating expected *Armillaria* damage to species selection and seed source after disturbance.

REFERENCES

Anon. 1982. Forest pathology - conifer plantations. In: Report on research activities for 1980-81. Australia: Queensland Department of Forestry, Division Technical Services: 52-54.

Bega, R. V. 1979. Heart and root rot fungi associated with deterioration of *Acacia koa* on the island of Hawaii. Plant Disease Reporter. 63: 682-684.

Carey, A. C.; Miller, E. A.; Geballe, G. T.; Wargo, M.; Smith, W. H.; Siccama, T. G. 1984. *Armillaria mellea* decline of red spruce. Plant Disease. 68: 794-795.

Cooper, S. T.; Neiman, K.; Steele, R.; Roberts, D. W. [In press]. Forest habitat types of northern Idaho: a second approximation. Gen. Tech. Rep. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Dunbar, D. M.; Stephens, G. R. 1975. Association of two-lined chestnut borer and shoestring fungus with mortality of defoliated oak in Connecticut. Forest Science. 21: 169-174.

Ehrlich, J. 1939. A preliminary study of root disease in western white pine. Stn. Pap. 1. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Rocky Mountain Forest and Range Experiment Station. 10 p.

Filip, G. M. 1977. An *Armillaria* epiphytic on the Winema National Forest, Oregon. Plant Disease Reporter. 61: 708-711.

Filip, G. M.; Goheen, D. J. 1982. Tree mortality caused by root pathogen complex in Deschutes National Forest, OR. Plant Disease. 66: 240-243.

Garrett, S. D. 1960. Rhizomorph behavior in *Armillaria mellea* (Fr) Quel. III. Saprophytic colonization of woody substrates in soil. Annals of Botany. 24: 275-285.

Hobbs, S. D.; Partridge, A. D. 1979. Wood decays, root rot, and stand composition along an elevation gradient. Forest Science. 25: 31-42.

Hubert, E. E. 1950. Root rot of the western white pine type. Northwest Science. 24: 5-17.

James, R. L.; Stewart, C. A.; Williams, R. E. 1984. Estimating root disease losses in northern Rocky Mountain National Forests. Canadian Journal of Forest Research. 14: 652-655.

Kile, G. A. 1980. Behavior of an *Armillaria* in some *Eucalyptus obliqua* – eucalyptus regions forests in Tasmania and its role in their decline. European Journal of Forest Pathology. 10: 278-296.

Kile, G. A. 1983. Identification of genotypes and the clonal development of *Armillaria luteobubaline* (Watling and Kile) in eucalypt forests. Australian Journal of Botany. 31: 657-671.

Leach, R. 1939. Biological control and ecology of *Armillaria mellea* (Wahl) Fr. Transactions of the British Mycological Society. 287: 320-329.

Likens, G. E. 1985. An experimental approach for the study of ecosystems: the Fifth Tansley Lecture. Journal of Ecology. 73: 381-396.

Madziara-Borusiewicz, K.; Strzelecka, H. 1977. Conditions of spruce (*Picea excelsa* Lk.) infestation by the engraver beetle (*Ips typographus* L.) in mountains of Poland. I. Chemical composition of volatile oils from healthy trees and those infested with the honey fungus (*Armillaria mellea* [Vahl] Quel). Zeitschrift fuer Angewandte Entomologie. 83: 409-415.

McDonald, G. I.; Martin, N. E.; Harvey, A. E. [In press]. Occurrence of *Armillaria* spp. in forests of the Northern Rocky Mountains. Res. Pap. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Morrison, D. J. 1982. Variation among British isolates of *Armillaria mellea*. Transactions of the British Mycological Society. 78: 459-464.

Morrison, D. J.; Chu, D.; Johnson, A. S. S. 1985. Species of *Armillaria* in British Columbia. Canadian Journal of Plant Pathology. 7: 242-246.

Neiman, Ken E. 1984. [Personal communication]. Ecologist, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Pronos, J.; Patton, R. F. 1977. *Armillaria* root rot of red pine planted on oak sites in Wisconsin. Plant Disease Reporter. 61: 955-958.

Raabe, R. D.; Trujillo, E. J. 1963. *Armillaria mellea* in Hawaii. Plant Disease Reporter. 47: 776.

Rishbeth, J. 1982. Species of *Armillaria* in southern England. Plant Pathology. 31: 9-17.

Redfern, D. B. 1973. Growth and behavior of *Armillaria mellea* rhizomorphs in soil. Transactions of British Mycological Society. 61: 569-581.

Redfern, D. B. 1978. Infection of *Armillaria mellea* and some factors affecting host resistance and the severity of disease. Forestry. 15: 121-135.

Rehfeldt, G. E. 1982. Differentiation of *Larix occidentalis* populations from the Northern Rocky Mountains. Silvae Genetica. 31: 13-19.

Rehfeldt, G. E.; Hoff, R. J.; Steinhoff, R. J. 1984. Geographic patterns of genetic variation in *Pinus monticola*. Botanical Gazette. 145: 229-239.

Rykowski, K. 1981. The influence of fertilizers on the occurrence of *Armillaria mellea* in Scots pine plantations. European Journal of Forest Pathology. 11: 108-119.

Shaw, C. G., III. 1977. *Armillaria* isolates from pine and hardwoods differ in pathogenicity to pine seedlings. Plant Disease Reporter. 61: 416-418.

Shaw, C. G., III; Roth, L. F. 1978. Control of *Armillaria* root rot in managed coniferous forests: a literature review. European Journal of Forest Pathology. 8: 163-174.

Shaw, C. G., III; Roth, L. F.; Rolph, L.; Hunt, J. 1976. Dynamics of fire and pathogen as they relate to damage in a forest attacked by *Armillaria*. Plant Disease Reporter. 60: 214-218.

Singh, P.; Raske, A. G. 1983. *Armillaria* root rot in spruce-budworm-damaged balsam fir stands. CANUSA Newsletter 26. Washington, DC: U.S. Department of Agriculture, Forest Service, Canada-United States Spruce Budworm Program.

Singh, P.; Richardson, J. 1973. *Armillaria* root rot in seeded and planted areas in Newfoundland. Forestry Chronicle. 49: 180-182.

Smith, W. H. 1984. Ecosystem pathology: a new perspective for phytopathology. Forest Ecology and Management. 9: 193-219.

Snedecor, G. W. 1956. Statistical methods. Ames, IA: Iowa State University Press. 534 p.

Steele, R.; Pfister, R. D.; Kittams, J. A. 1981. Forest habitat types of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

Swift, M. J. 1972. The ecology of *Armillaria mellea* Vahl. (en Frier) in the indigenous and exotic woodlands of Rhodesia. Forestry. 45: 67-86.

Wargo, P. M. 1977. *Armillaria mellea* and *Agrilus bilineatus* and mortality of defoliated oak trees. Forest Science. 23: 485-492.

Wargo, P. M. 1981. Defoliation and secondary-action organism attack: with emphasis on *Armillaria mellea*. Journal of Arboriculture. 7: 64-69.

Wargo, P. M. 1984. How stress predisposes trees to attack by *Armillaria mellea* - a hypothesis. In: Kole, G. S., ed. Proceedings, sixth IUFRO conference root butt rots in forest trees. Melbourne, Australia: CSIROM Melbourne: 115-122.

Wargo, P. M.; Shaw, C. G., III. 1985. *Armillaria* root rot—the puzzle is being solved. Plant Disease. 69: 826-832.

Williams, R. E.; Marsden, M. A. 1982. Modeling probability of root disease center occurrence in northern Idaho forests. Canadian Journal of Forest Research. 12: 876-882.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

USDA policy prohibits discrimination because of race, color, national origin, sex, age, religion, or handicapping condition. Any person who believes he or she has been discriminated against in any USDA-related activity should immediately contact the Secretary of Agriculture, Washington, DC 20250.

United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-372

Soil Disturbance-Tree Growth Relations in Central Idaho Clearcuts

James L. Clayton
Gary Kellogg
Neal Forrester[1]

ABSTRACT

Two central Idaho clearcuts regenerated naturally to lodgepole pine (Pinus contorta) *and one regenerated with planted ponderosa pine* (Pinus ponderosa) *were evaluated to see if soil compaction and displacement affected growth as measured by tree height, diameter at breast height, and radial growth increment. Pole-sized trees ranging in age from 15 to 25 years occupy the sites, and soils contain considerable volcanic ash in the surface 30 cm. Significant (90 percent level) declines in one or more growth attributes were associated with increased penetration resistance and lateral soil displacement at all three sites. One site had significant (99 percent level) growth declines associated with increased soil bulk density. Results of these studies suggest that steps to minimize lateral soil displacement and compaction are required to maintain potential productivity levels on these soils.*

KEYWORDS: soil compaction, growth declines, lodgepole pine, ponderosa pine

Yarding logs with ground skidders, either crawler tractor or rubber-tired skidders, can cause considerable soil disturbance. Megahan (1980) summarized results from 16 logging studies in the United States and Canada and found that the average percentage of area disturbed by ground skidding (excluding roads) is 21 percent, and includes lateral soil displacement, horizon mixing, and compaction. This disturbance affects the soil resource both positively and negatively. Minor displacement or mixing is often cited as beneficial for regeneration because it prepares a seedbed and reduces competing vegetation. On the other hand, soil disturbance reduces soil cover that affords protection from erosion, disrupts soil biological processes important to nutrient cycling, and can change soil physical properties to the detriment of plant production.

Lateral soil displacement can cause localized productivity losses on a site in similar fashion to the more generalized losses resulting from erosion. In addition, accelerated erosion is an almost universal consequence of forest soil disturbance (Gilmour 1977; Hewlett 1979; O'Loughlin and others 1980; Rice and Datzman 1981). The potential productivity loss accompanying soil displacement or erosion in forested ecosystems is poorly understood. For decades soil loss tolerance levels for nonforested agricultural lands have been studied and tolerance levels established, although the soil loss productivity relationship is still not well defined (National Soil Erosion-Soil Productivity Research Planning Committee 1981). Rice and others (1972) point out that soil loss from logging activities rarely occurs uniformly over the logged area and tends to be localized. These authors suggest that much less degradation of site quality is expected than would be the case if erosion were more uniform over the whole surface. Lateral soil displacement also disrupts biological processes that play an important role in terms of (1) soil nutrient levels and availability, (2) decay of woody plant material, and (3) activities of plant pathogens (Jurgensen and others 1979). Timber harvest activities that disturb surface soil may accelerate decomposition and mineralization resulting in increased leaching and nutrient loss. Displacement of organic matter may also adversely affect soil physical properties.

In addition to erosion and surface biological effects, ground skidding may adversely affect soil physical properties by compaction. Forristall and Gessel (1955) in Snohomish County, WA, found that increased bulk density from compaction impeded root growth. Western redcedar (*Thuja plicata*) tolerated densities to 1.8 Mg/m^3, red alder (*Alnus rubra*) to 1.5 Mg/m^3, and Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) to only 1.3 Mg/m^3. Daddow and Warrington (1983) reviewed results of several published studies and concluded that growth-limiting bulk densities are texture dependent. They suggested that soils with a large amount of fine particles (silt plus clay) will have lower growth-limiting bulk densities than will coarse-textured sandy soils. Their predictions for growth limitations are restricted to soils with less than 10 percent gravel, a severe limitation for many forest soils. In addition, they were unable to make predictions about productivity loss because of the lack of published data relating productivity to compaction. Helms (1983) studied compaction effects on two ponderosa pine stands in California and concluded that bulk density accounted for

---

[1] James L. Clayton is a research soil scientist located at the Intermountain Research Station's Forestry Sciences Laboratory, Boise, ID. Gary Kellogg and Neal Forrester are soil scientist and forester, respectively, Nez Perce National Forest, Grangeville, ID.

10 to 20 percent of the variability in height growth. Volume production per acre showed a reduction of 20 percent due to compaction for both stands. Wert and Thomas (1981) documented Douglas-fir productivity declines on skid-roads in western Oregon. Volume losses of 12 percent for the entire area were reportedly due to compaction along skid trails, and this caused both lower stand density and reduced volume growth. Froehlich and others (1983) suggest that there is a predictable relationship between percentage decrease in seedling height growth and percentage increase in soil density based on six United States studies.

Published data relating soil disturbance to productivity are unavailable for the Northern Rocky Mountain Province forest lands. Few studies document the extent and longevity of soil compaction caused by logging activities in this area. Froehlich and others (1983) studied compaction along skid trails on soils formed from granitic and volcanic parent materials in central Idaho. They concluded that compaction as measured by increased bulk density is present on both soils, and they predicted effects will last 45 years. They made no evaluation of productivity loss due to compaction.

This paper reports results of a study conducted in the Nez Perce National Forest, north-central Idaho. Three stands, clearcut in the 1960's and yarded with a crawler tractor, were independently evaluated for soil disturbance and tree growth in order to test if productivity is correlated with soil disturbance. Soil disturbance evaluations included measurements of bulk density, resistance to penetration, and lateral soil displacement. Tree growth was measured by tree height, diameter, and radial growth increment. Soils on two of the sites are formed from quartzites, gneisses, and schists of the Belt Supergroup; soils of the third site are formed from basalt of the Grande Ronde formation. All soils have a considerable volcanic ash content in the surface 30 cm. These soils are widespread in northern and north-central Idaho forests and are probably subject to compaction when disturbed.

The objectives of this study were (1) to determine if there are impacts on site productivity as measured by tree growth resulting from the cumulative effects of soil disturbance on a "typical" harvest unit and (2) to develop a practical and inexpensive methodology for monitoring management practices on soil productivity.

SITE DESCRIPTIONS

The Deadwood study site is an 11-ha clearcut located in the S½ sec. 16, T. 28 N., R. 8 E., on the Elk City Ranger District, Nez Perce National Forest. Median elevation is 1,485 m. Slopes range from 0 to 10 percent and have a southwest aspect. The habitat type (Cooper and others 1985) is grand fir/beargrass (*Abies grandis/Xerophyllum tenax*). Mean annual precipitation is 102 cm, most of which falls as snow in the winter. Soils are classified as coarse-loamy, mixed, frigid, Andic Dystrochrepts, and typically have a loam or silt loam surface texture. Soils are formed on metamorphic rocks of the Belt Supergroup, but have a significant volcanic ash content in the surface 30 cm. Soils are deep and well-drained. The site was clearcut in 1969. Crawler tractors were used to log the stand, and slash was broadcast burned in 1970. Engelmann spruce (*Picea engelmannii*) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) were planted in 1971, but lodgepole pine (*Pinus contorta*) has regenerated naturally and is the dominant species. The average stand age is 15 years.

The Dawson Creek site is a 7.5-ha clearcut located in t NW¼ sec. 25 and the SW¼ sec. 24, T. 28 N., R. 8 E., o the Red River Ranger District, Nez Perce National Fores Slopes range from 0 to 10 percent and face southeast at an average elevation of 1,475 m. The habitat type is gra fir/beargrass. Mean annual precipitation is 102 cm. Soils are coarse-loamy, mixed, Eutric Glossoboralfs with a silt loam surface texture, are well-drained and deep, and are formed on metamorphic rock but with volcanic ash in the top 30 cm. The site was clearcut in 1966 and yarded with a crawler tractor, and slash was tractor piled and burned The stand regenerated naturally to lodgepole pine and w precommercially thinned in 1979. The approximate stand age is 19 years.

The Shell's Lick site is a 20-ha clearcut located in the W½ sec. 6, T. 27 N., R. 3 E., on the Slate Creek Ranger District, Nez Perce National Forest. Slopes range from 0 to 10 percent and face west at an average elevation of 1,730 m. The habitat type is grand fir/beargrass. Mean annual precipitation is 115 cm. Soils are loamy-skeletal, mixed, Andic Cryochrepts with a silt loam or gravelly sil loam surface texture. Soils are well-drained and moderately deep, formed on basalt from the Grande Ronde formation, and contain ash in the top 30 cm. The site was clearcut in 1961 and the logs yarded with a crawler tractor. The exact method of slash disposal is unknown, but was probably a combination of tractor piling, jackpot burning, and broadcast burning. Ponderosa pine (*Pinus ponderosa*) was planted on a 2- by 2-m spacing starting i 1961 and ending in 1964. The current stand is 20 to 25 years old.

METHODS

Field Procedures

Independent estimates of tree growth and soil disturbance were made at each study site in 1984. Sites were characterized as to soil lateral displacement by machiner soil bulk density, and resistance to penetration in the following manner: All undamaged trees greater than 7.5 cm diameter at breast height (5 cm at Deadwood) constituted the population of plot centers for soil disturbanc estimates in each clearcut. For lateral soil displacement, the crown drip line delineated the approximate boundary within which displacement was estimated. Three classes displacement were considered:

1. None-slight: generally no sign of lateral soil displacement within the crown drip line area; if minor lateral soil displacement occurred, it occurred on less than 25 percen of the area.
2. Moderate: 25 to 49 percent of the crown drip line area has lateral soil displacement, or greater than 25 percent of the area has been laterally displaced, but surface soil is still present on displaced areas.
3. High: 50 percent or more of the area within the crown drip line has been laterally displaced.

Because it had been approximately 20 years since the disturbing activity, evidence for lateral soil displacement was not always readily apparent. We defined displacement as removal of part or all of the surface soil (top 30 cm) that would occur on the plot assuming all plots had a soil profile similar to that on adjacent undisturbed sites. We feel this is reasonable in view of the uniformity of soils on these relatively stable slopes.

At the Deadwood site, three bulk density core samples were taken in each plot at 120-degree intervals around the drip line of each tree. Single cores were taken at each plot at Dawson Creek and Shell's Lick sites. Cores were driven vertically into the soil using a 295-cm^3 coring device having a length of 17 cm and a diameter of 4.7 cm.

Resistance to penetration was estimated subjectively using a "sharpshooter" soil surveyor's shovel, which is essentially a long-bladed spade. The blade of the shovel was pressed by foot through the surface 17 cm of soil at three locations on each plot in a fashion similar to the coring done at the Deadwood site, taking care to avoid the soil disturbed during coring. The individual doing the penetration tests first sampled several areas that were undisturbed by logging to learn to recognize natural soil conditions, then sampled several skid-road locations to learn to recognize penetration resistance due to compaction. These two subjective measurements constitute our slight and high resistance levels, respectively. Anything in between was given a level of moderate. To test if this procedure in fact had any validity, we independently double sampled another study area with both the sharpshooter shovel and a 30-degree cone penetrometer. Penetration classes determined by shovel of low, medium, and high had penetrometer values (mean ± standard error) of 685 ± 48, $1{,}110 \pm 49$, and $1{,}705 \pm 49$ kPa, respectively. This suggests that real and consistent differences in penetration resistance can be estimated with a shovel.

Tree Sampling

Plot centers were located in all three stands using a 20- by 20-m square spacing. A starting point was selected randomly, and a square grid was established systematically using cardinal compass directions from the starting point. At each plot center a 2-m radius circular plot was used to determine which trees would be measured. Individual tree measurements were taken using the Forest Service Northern Region's Stand Exam Guidelines (USDA Forest Service 1985). Height was measured to the nearest 3 cm using a measuring rod, and diameters were measured to the nearest 0.25 cm. Every tree over 7.5 cm diameter at breast height (d.b.h.) was bored to determine the age and radial growth increment at breast height. The radial growth was measured for the previous 10 growing seasons and recorded to the nearest 0.1 cm.

Stocking comparisons for the various soil disturbance groupings at Shell's Lick and Deadwood were made using the Northern Region's Basic Stand Tables Edit routine to judge if differences in growth parameters might be due to competition. The mean number of trees per hectare and 95 percent confidence interval by disturbance class (low, medium, high) for each disturbance type (displacement, soil density, penetration resistance) was projected. At Deadwood and Shell's Lick, stocking showed slight declines with increasing disturbance, but all confidence intervals overlapped. Stocking was more uniform at Dawson Creek, which had been precommercially thinned, and again all confidence intervals overlapped. Mean stockings at Deadwood, Shell's Lick, and Dawson are 2,480, 1,037, and 2,200 trees per hectare, respectively. Although stocking is different between sites, there is no reason to suspect stocking differences among disturbance classes within a site contribute to growth differences.

Data Analysis

Soil displacement and penetration resistance classes were tested for effects on radial growth, diameter increment, and tree height using analysis of variance. A least significant difference (LSD) test was run on those groups that tested significant at the 90 percent level. Bulk density effects on growth were tested as a continuous variable using regression analysis. The effects of bulk density and penetration resistance on growth were examined together using covariance analysis with bulk density as a covariate.

RESULTS

The effects of soil displacement and resistance to penetration on d.b.h., radial growth, and height are presented in tables 1 and 2. Lateral soil displacement is associated with decreased d.b.h. at all three sites. Height growth and radial growth are lower on moderately and highly displaced soils at the Deadwood and Shell's Lick sites, but there is no statistical evidence for decreased growth at the Dawson site. Penetration resistance increases are associated with decreased d.b.h. at Deadwood and Dawson Creek but not at Shell's Lick. Height growth at Deadwood and Shell's Lick, and radial growth at Deadwood are lower on soils with moderate or high penetration resistance.

Radial growth, tree height, and d.b.h. exhibit statistically significant (99 percent level) negative correlations with increased soil bulk density at the Deadwood site but not at the other two sites. The following equations describe relationships at Deadwood:

$$\mathrm{RG} = 6.01 - 2.03\ \mathrm{BD};\ n = 28,\quad r^2 = 0.20,\ \mathrm{F} = 7.909^{**} \tag{1}$$

$$\mathrm{HT} = 5.7 - 1.74\ \mathrm{BD};\ n = 28,\quad r^2 = 0.32,\ \mathrm{F} = 13.73^{**} \tag{2}$$

$$\mathrm{d.b.h.} = 9.8 - 3.15\ \mathrm{BD};\ n = 28,\quad r^2 = 0.40,\ \mathrm{F} = 19.18^{**} \tag{3}$$

where

RG = radial growth in cm over the previous 10 years

BD = bulk density in Mg/m^3

HT = tree height in meters

d.b.h. = diameter breast height in cm.

Mean bulk density values for disturbed and undisturbed plots are presented for each study site in table 3. Increased bulk density from soil compaction was slight at Shell's Lick in the surface 17-cm core samples (0.82 to 0.94), but increased penetration resistance was more common. This suggests that a layer of increased soil strength,

Table 1—The effects of soil displacement on diameter at breast height (DBH), radial growth (RG), and tree height. Values are means for each displacement class; means with different letters are significantly different using a least significant difference test at the 10 percent level

Site	Displacement class	DBH	RG	Height	Plots
		cm	*cm/10 yr*	*m*	*Number*
Deadwood (lodgepole pine)	Slight	6.9 a	4.2 a	4.15 a	15
	Moderate	5.8 ab	3.3 ab	3.60 b	10
	High	5.1 b	3.0 b	2.44 c	3
Shell's Lick (ponderosa pine)	Slight	15.0 a	5.4 a	6.19 a	52
	Moderate	12.4 b	4.9 b	5.34 b	21
	High	11.7 b	4.3 c	4.85 b	9
Dawson Creek (lodgepole pine)	Slight	11.7 a	5.4 a	6.44 a	13
	Moderate	9.7 b	5.1 a	5.80 a	5
	High	9.9 b	5.1 a	5.86 a	13

Table 2—The effects of soil penetration resistance on diameter at breast height (DBH), radial growth (RG), and tree height. Values are means for each penetration resistance class; means with different letters are significantly different using a least significant difference test at the 10 percent level

Site	Penetration class	DBH	RG	Height	Plots
		cm	*cm/10 yr*	*m*	*Number*
Deadwood (lodgepole pine)	Slight	7.1 a	4.3 a	3.97 a	10
	Moderate	6.1 b	3.4 b	3.84 a	13
	High	5.3 b	3.2 b	2.96 b	6
Shell's Lick (ponderosa pine)	Slight	13.7 ab	4.9 a	5.73 a	32
	Moderate	14.5 b	5.1 a	6.10 a	40
	High	12.4 a	5.1 a	4.94 b	10
Dawson Creek (lodgepole pine)	Slight	13.0 a	5.7 a	6.77 a	5
	Moderate	10.4 b	5.0 a	6.01 a	20
	High	10.2 b	5.2 a	5.73 a	6

Table 3—Bulk density (0 to 17 cm) values at each study site. Mean (u) is the mean of all undisturbed plots and represents natural surface bulk density; mean (d) is the mean value for plots disturbed by logging

Site	Mean (u)	Standard deviation	Mean (d)	Standard deviation
	- - - - - - - -	- - - - - - - *Mg/m^3*	- - - - - - -	- - - - - - - -
Deadwood	0.90	0.13	1.30	0.19
Shell's Lick	.82	.05	.94	.11
Dawson Creek	.76	.10	1.15	.16

insufficient in thickness to cause significant growth declines with increasing bulk density, may have been present. There were no growth declines attributable to compaction (penetration or bulk density increase) at Shell's Lick except for a significant height loss associated with the high penetration resistance class.

At Dawson Creek there were significant increases in bulk density from 0.76 to 1.15 Mg/m^3, particularly in skid trails. D.b.h. declines were significantly correlated with penetration resistance at Dawson Creek (table 2) but not radial growth or height declines. D.b.h. declines did not test significant with increased bulk density at $\alpha = 0.1$, but did test significant at $\alpha = 0.2$. Although the bulk density increases expressed as a percentage over natural were greater at Dawson Creek than at Deadwood (table 3), mean bulk density of disturbed plots was greater at Deadwood, and this suggests that a threshold value is exceeded before growth declines result. These overall higher densities may be the reason why declines in all growth factors with increasing bulk density were found at Deadwood but not the other two sites.

An analysis of covariance on the data sets from all three sites was run with bulk density as a continuous covariate along with the three penetration resistance classes to test for interactions. Again, tests of bulk density effects on growth within penetration resistance classes at Shell's Lick and Dawson Creek showed that the differences among the means were not significant. When the effect of bulk density was removed from the model at Deadwood, penetration resistance classes exhibited no significant effect on growth. Note that penetration resistance had a significant effect on all three growth factors at Deadwood in the one-way analysis of variance. In addition, adjusted means for growth response for each penetration resistance class in the covariance analysis were similar to means in the one-way analysis. This suggests that density and penetration resistance tests may be measuring the same effect on growth factors, and one might select either for soil monitoring purposes.

DISCUSSION

Productivity losses resulting from soil disturbance are difficult to predict. Actual losses depend on the percentage of area impacted, associated growth decline for a given level of impact, and the rate of recovery. Percentage of area impacted is relatively easy to estimate (and manage), and our results give an estimate of growth decline for a single point in the stand life by disturbance level. For example, moderate soil displacement at Shell's Lick resulted in mean declines of 17 percent, 9 percent, and 14 percent in d.b.h., radial growth, and height, respectively, compared to undisturbed soils. High soil displacement resulted in an additional decline of 12 percent in radial growth. Based on parabaloid bole volume estimates, current volume reductions of 40 percent and 53 percent are realized from the growth reductions associated with moderate and high displacement of soils at Shell's Lick. Similarly, calculations of volume losses associated with penetration resistance at the Deadwood site suggest a current volume loss of 44 percent on those sites placed in the high penetration resistance class. At the Deadwood site calculations could be made for volume losses associated with increased bulk densities because significant growth declines were observed.

Recovery rates following soil disturbance are a currently unknown factor, and this uncertainty makes any estimates of increases in length of rotation or volume loss at rotaion for the stand highly speculative. However, we feel hat lateral soil displacement effects result in a long-term mpact that is not readily reversed. Recently published ata by Froehlich and others (1985) suggest that increased oil densities from compaction during logging activity night not recover for longer than 25 years except near he surface in granitic soils, and may take longer than 40 ears in the 15- to 30-cm depth zone in soils formed from olcanic parent materials in central Idaho. Soil recovery rom increased resistance to penetration would likely arallel bulk density declines, although this is not certain. No data are available on recovery rates from soil displacement that can be logically related to tree growth response. thers have used such factors as long-term estimates of soil formation rates to define soil loss tolerance for farmand agriculture. However, the intensities of various soil-forming factors on forested slopes are different and inadequately defined to estimate recovery of biological productivity.

Although our data are not adequate to estimate the long-term productivity consequences of the observed growth losses in this study, we feel that the growth losses attributed to lateral displacement and compaction will either extend the length of time required to produce merchantable timber or result in volume losses at harvest.

CONCLUSIONS

The results of this study suggest that soil displacement and compaction from logging activities, brush disposal, and site preparation work can adversely affect growth of the regenerating stand. Significant (90 percent level) declines in one or more growth attributes were associated with increased penetration resistance and soil displacement at all three sites. Only one site, Deadwood, showed significant growth declines associated with increased soil bulk density (99 percent level). Our data are not adequate to predict productivity losses over a rotation. However, the growth declines observed in pole-sized trees are likely to result in extended rotations (assuming rotations are determined by culmination of mean annual growth) or reduced volumes even assuming immediate amelioration of the soil problems.

Several options are available to avoid or minimize productivity losses. Use of low ground pressure equipment, avoiding operations when the soil is wet, or logging over snow may avoid compaction effects altogether. Ripping has been used successfully to reverse compaction (Greacen and Sands 1980). Dedicated skid trails allow managers to control the percentage of area adversely impacted. Careful use of blades during slash piling or site preparation will reduce impacts of soil displacement.

Future studies are needed in the Northern Rocky Mountains to determine how long soil disturbance effects persist and the long-term effects of these disturbances on site productivity.

REFERENCES

Cooper, Stephen; Neiman, Kenneth; Steele, Robert. 1985. Forest habitat types of northern Idaho. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Northern Region. 185 p. Editorial draft.

Daddow, R. L.; Warrington, G. E. 1983. Growth-limiting bulk densities as influenced by soil texture. Group Report WSDG-TN-00005. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Watershed Systems Development Group. 17 p.

Forristall, F. F.; Gessel, S. P. 1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish Co., Washington. Soil Science Society of America Proceedings. 19: 384-389.

Froehlich, H. A.; Miles, D. W. R.; Robbins, R. W. 1985. Soil bulk density recovery on compacted skid trails in central Idaho. Soil Science Society of America Journal. 49: 1015-1017.

Froehlich, H. A.; Miles, D. W.; Robbins, R.; Lyons, J. K. 1983. Soil monitoring project report on Payette National Forest and Boise Cascade lands. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Payette National Forest, McCall, ID.

Gilmour, D. A. 1977. Logging and the environment, with particular reference to soil and stream protection in tropical rainforest situations. In: Conservation guide 1: guidelines for watershed management. Rome: Food and Agriculture Organization: 223-225.

Greacen, E. L.; Sands, R. 1980. Compaction of forest soils: a review. Australia Journal of Soil Research. 18: 163-189.

Helms, J. A. 1983. Soil compaction and stand growth. Unpublished final report to U.S. Department of Agriculture, Forest Service, on file at: University of California, Department of Forest Resources Management, Berkeley, CA. 97 p.

Hewlett, J. D. 1979. Forest water quality: an experiment in harvesting and regenerating Piedmont Forest. Research Paper. Athens, GA: University of Georgia, School of Forest Resources. 22 p.

Jurgensen, M. F.; Larsen, M. J.; Harvey, A. E. 1979. Forest soil biology-timber harvesting relationships. Gen. Tech. Rep. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Megahan, W. F. 1980. Nonpoint source pollution from forestry activities in the western United States: results of recent research and research needs. In: Proceedings of forestry and water quality: what course in the 80's? An analysis of environmental and economic issues. Washington, DC: Water Pollution Control Federation: 92-151.

National Soil Erosion-Soil Productivity Research Planning Committee, Science and Education Administration-Agricultural Research. 1981. Soil erosion effects on soil productivity: a research perspective. Journal of Soil and Water Conservation. 36: 82-90.

O'Loughlin, C. L.; Rowe, L. K.; Pearce, A. J. 1980. Sediment yield and water quality responses to clearfelling of evergreen mixed forests in western New Zealand. International Association of Scientific Hydrology. 130: 285-292.

Rice, R. M.; Datzman, P. A. 1981. Erosion associated with cable and tractor logging in northwestern California. International Association of Scientific Hydrology. 132: 362-374.

Rice, R. M.; Rothacher, J. S.; Megahan, W. F. 1972. Erosional consequences of timber harvesting: an appraisal. In: Proceedings, national symposium on watersheds in transition. Urbana, IL: American Water Resources Association: 321-329.

U.S. Department of Agriculture, Forest Service. 1985. Timber management data. Handb. FSH 2409.21h. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region.

Wert, S.; Thomas, B. R. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas-fir. Soil Science Society of America Journal. 45: 629-632.

September 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-373

Adaptive Variation and Seed Transfer for Ponderosa Pine in Central Idaho

G. E. Rehfeldt[1]

ABSTRACT

When planted and compared in the same environments, populations from elevationally or geographically mild sites demonstrated the most growth, mainly because of the long duration and rapid rate of shoot elongation. Populations from relatively cold sites were comparatively shorter largely because growth ceased early. Populations from the South Fork of the Salmon River, however, combined a high rate of shoot elongation with a short duration of growth and thereby were capable of high productivity while maintaining adaptability for severe sites. In artificial reforestation, seed transfer from most populations should be limited to ±650 feet of the elevation at the source. Tests should be established to determine if South Fork populations can be moved beyond the recommended limits in an attempt to increase productivity on harsh, cold sites.

KEYWORDS: *Pinus ponderosa*, seed zones, reforestation, forest genetics, ecological adaptation

Plant populations that occupy contrasting environments commonly differ genetically for numerous traits that convey environmental adaptation. In forest trees, physiological attunement to the environment is commonly displayed in traits that comprise an annual sequence of developmental events. This sequence begins with bud burst in the spring; includes shoot expansion, leaf maturation, cambial enlargement, bud development, and lignification; and concludes with cold acclimation in the fall. For populations to be adapted, the entire sequence must be completed within the growing season, a period terminated by frost but often interrupted by drought. Adaptive differentiation thus results from physiologic attunement of the entire sequence of developmental events to a growing season whose length varies considerably among sites and years. Consequently, the timing of individual events within the developmental cycle tend to be intercorrelated.

When Rocky Mountain populations of ponderosa pine are grown in common environments, populations from mild environments exhibit a long duration and late cessation of shoot elongation; a long length and late maturation of leaves; a late date for completion of lignification; and a tall stature associated with a high growth potential (innate capacity for growth). A late cessation of development, however, conveys a high susceptibility to fall frosts, and a high growth potential reflects susceptibility to snow damage. By contrast, populations adapted to short growing seasons cease development early, display a low growth potential, but are most tolerant of early fall frosts and heavy snows (Madsen and Blake 1977; Rehfeldt 1979b, 1980, 1986a, 1986b).

Because genetic differentiation occurs along environmental gradients, genetic variation is clinal (continuous) and can be described as systematic patterns of variation across geographic and elevational gradients. The clines, therefore, are basic to the development of seed transfer guidelines, the environmental limits to which seeds can be transferred from their origin before maladaptations begin reducing the productivity of artificial reforestation.

This paper is the second in a series devoted to describing genetic variation among populations of ponderosa pine in central Idaho. The first paper (Rehfeldt 1986a) detailed experimental methods and statistical procedures and applied general results to concepts of adaptive variation. The present paper refines statistical procedures to describe adaptive clines and develop seed transfer guidelines specifically for the Salmon River Mountains.

METHODS

Population differentiation was studied in seedlings from 64 populations (appendix) that sampled the ecologic, geographic, and elevational distribution within which the species is of commercial importance in central Idaho (fig. 1). As detailed previously (Rehfeldt 1986a), cones were collected in a manner to adequately sample genetic diversity, and seedlings were compared in separate studies of (1) growth and development in the field, (2) the periodicity of shoot elongation in the greenhouse, and (3) freezing tolerance in the laboratory.

---

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

Figure 1—Geographic distribution of ponderosa pine (shading) and location of sampled populations. Letters A to G locate the elevational clines presented in figure 2.

Twelve variables originally were used to assess genetic variation for several events within the annual sequence. Because events within the sequence are intercorrelated, a relatively small number of variables can be used as keys to describing genetic variation within the entire sequence. In this paper, 3-year height and the rate and duration of shoot elongation are used to reassess patterns of genetic variation according to models that are developed for practical application.

Selection of a regression model that best described patterns of genetic variation required screening several models of the general form:

$$Y_{ij} = b + \sum_{j} \beta X_{ij} + \sum_{j} \gamma X_{ij}^{2}$$

where Y_{ij} is one of three dependent variables for population i in subregion j (fig. 1); X's are independent variables describing the origin of population i, and b, β, and γ are regression coefficients.

Because the objectives of the regression analyses were to detect and describe patterns of genetic variation, a large number of independent variables were screened for association with the dependent variables. Independent variables included elevation, latitude, longitude, northwes departure, southwest departure, arcs of a circle centered at 44° latitude and 114° longitude, and the squares of all variables. Northwest and southwest departures were obtained by rotating the grid of longitude and latitude by 45°. The five geographic variables were also nested withi three geographic subregions (fig. 1). Thus, 32 independen variables were screened by stepwise regressions for maximizing R^2 (SAS 1982). The best fitting regression model was selected according to the following criteria (Draper and Smith 1981): statistical significance, smallest residua variance, no relationship between residuals and independent variables, and no evidence of overfitting—the fitting of a model to individual samples rather than to the grou as a whole.

RESULTS AND DISCUSSION

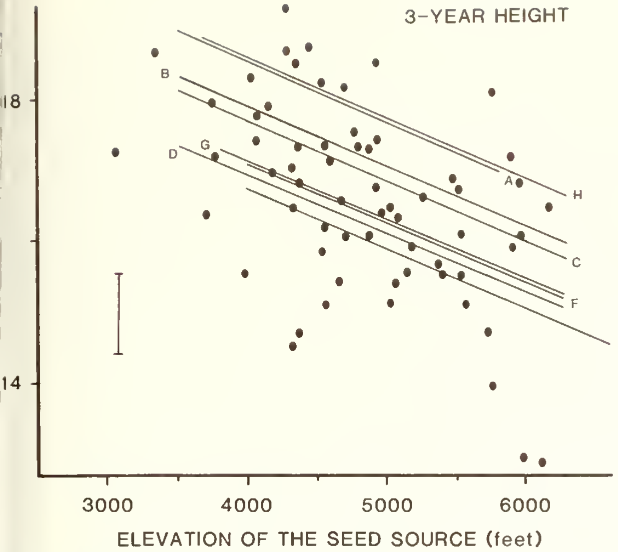
The best fitting regression models were all statistically significant ($p<0.01$) and accounted for 67 percent of the variance among populations in 3-year height, 48 percent for the rate of shoot elongation, and 68 percent for the duration of shoot elongation. The models included 14 to 18 independent variables and thereby could reflect overfi ting. Consequently the practical significance of a model i interpreted according to the least significant difference (Steel and Torrie 1960) among populations at the 80 percent level of probability (*lsd* 0.2). A relatively low level o probability is used to guard against accepting no differences among populations when differences actually exist.

Patterns of genetic variation described by the models can be presented as elevational clines for several geographic localities (figs. 2 and 3) or by geographic clines f a constant elevation (figs. 4 and 5). In figures 2 and 3, th elevational clines are presented for eight localities whose geographic position is keyed to figure 1:

Symbol	Locality
A	Lower Boise River
B	Council
C	Idaho City
D	Lowman
E	North Fork
F	Featherville
G	New Meadows
H	South Fork

The elevational clines (figs. 2 and 3) show that populations from the rather mild environments at low elevation tend to be tall because of a long duration of shoot elonga tion. Populations from high elevations, where frost-free periods are short, have a short duration of elongation an a low growth potential. The slope of these clines implies that at any locality, populations separated by about 1,300 feet differ by an amount equal to *lsd* 0.2. Thus, suc populations differ genetically with a probability of about 80 percent.

The elevational clines also illustrate that populations of similar genetic constitution recur at different elevations across the landscape. Populations of a moderate duration,



igure 2—Elevational clines for the 3-year
eight of seedlings from eight geographic loca-
ons keyed to figure 1. Brackets quantify *lsd*
.2.

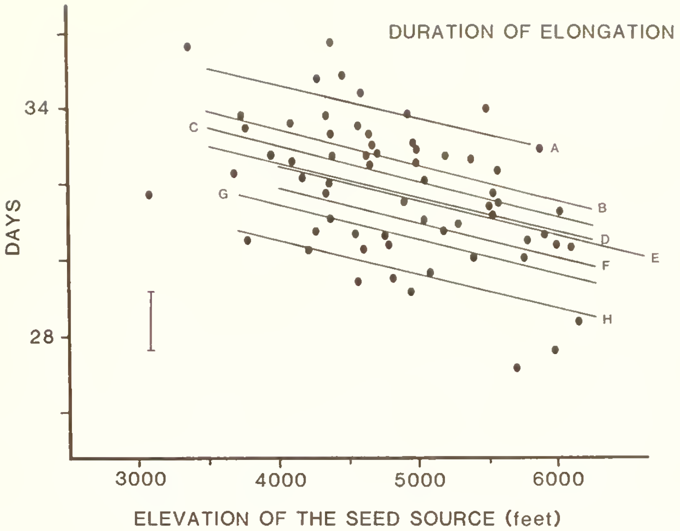
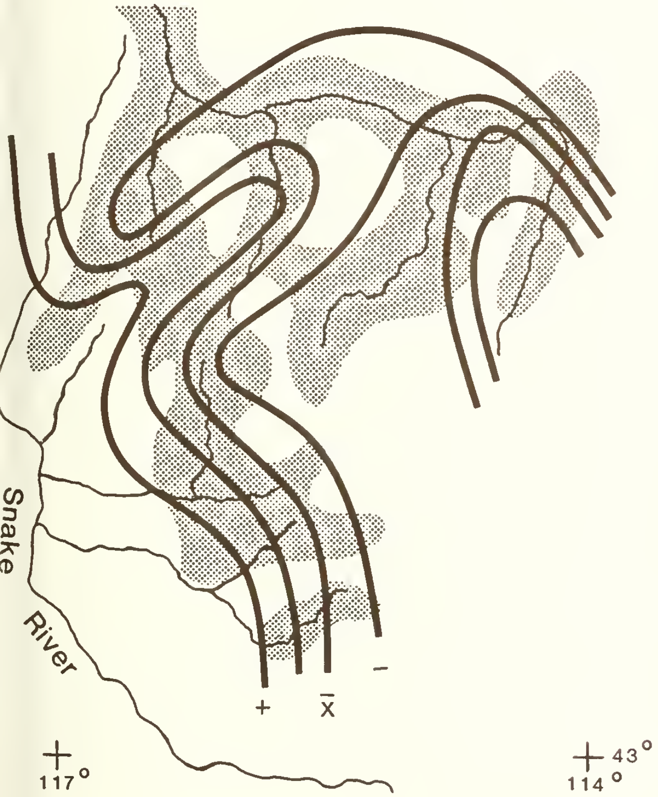
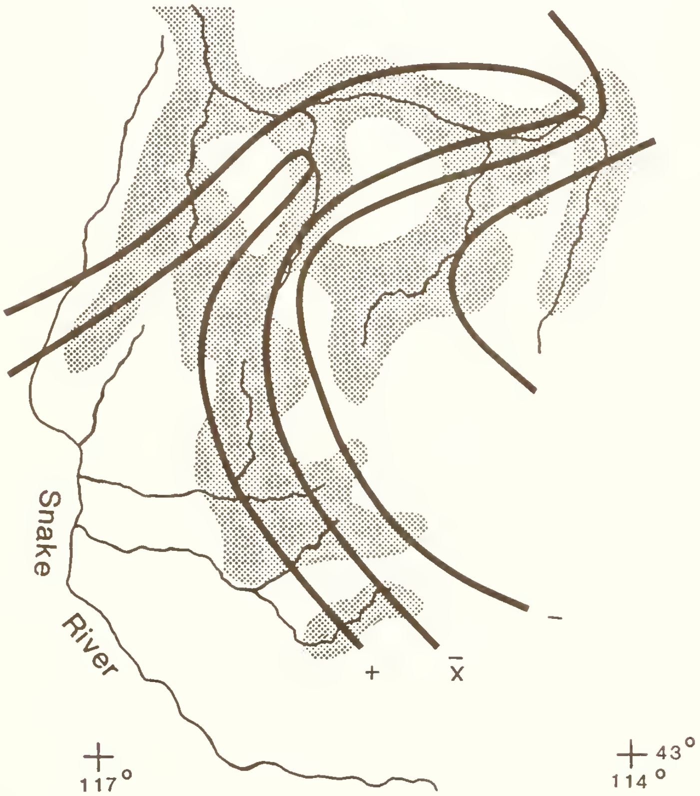


Figure 3—Elevational clines for the duration of shoot elongation of seedlings from eight geographic localities keyed to figure 1. Brackets quantify *lsd* 0.2.



HEIGHT

igure 4—Geographic patterns of variation for
3-year height described by isopleths (contour
ines) of equal performance at the mean eleva-
ion (3,500 feet). The interval between isopleths
equals ½[*lsd*(0.2)]. Isopleths represent positive
or negative deviations from the mean value ($\bar{x}$)
of all populations.



RATE OF ELONGATION

Figure 5—Geographic patterns of variation for rate of shoot elongation described by isopleths (contour lines) of equal performance at the mean elevation (3,500 feet). The interval between isopleths equals ½[*lsd*(0.2)]. Isopleths represent positive or negative deviations from the mean value ($\bar{x}$) of all populations.

33 days for example (fig. 3), would be expected to occur at 3,500 feet at Lowman, 4,000 feet at Idaho City, and 5,000 feet at Council. This also means that populations growing at the same elevation in different geographic localities can be different genetically. Of all populations from an elevation of 5,000 feet, for example, those from the South Fork and Lower Boise River have the greatest growth potentials while those from the North Fork have the lowest. Recurrence of similar genotypes is dependent on the recurrence of environments with similar growing season, the environmental factor primarily responsible for adaptive differentiation. Consequently, populations of similar adaptive norms are distributed across the landscape in patterns that are oblique to elevation.

Geographic patterns of genetic variation are detailed in figures 4 and 5 for 3-year height and the rate of shoot elongation, respectively. In these figures, the distance between isopleths (contour lines) equals ½*lsd*(0.2). This means that localities separated by the distance between two isopleths support populations that are genetically different, with a probability of about 80 percent. According to figure 4, populations of greatest growth potential occur in those environments at relatively low elevations that are adjacent to the steppe, exactly where ponderosa pine is ecologically dominant (Steele and others 1981). Toward the north, northeast, and east, the climate is strongly influenced by particularly massive mountains. As a result, growth potentials decline as the frost-free period declines. Figure 5 depicts a similar pattern for the rate of shoot elongation: populations of highest growth potential also tend to have the fastest rates of elongation.

These figures together show that populations with the highest growth potential tend to originate from the mildest environments and achieve a high potential by means of a long duration and rapid rate of shoot elongation. A notable exception to this generality involves populations from the South Fork where a mild growing season is commonly truncated by drought. These populations express a high growth potential (fig. 3) that is achieved by means of a high rate of shoot elongation (fig. 5) despite having the shortest duration of elongation (fig. 2) of any populations tested. South Fork populations, therefore, express a growth potential that is typical of populations from mild environments while maintaining a short duration of elongation, which is typical of populations adapted to cold sites. Superior performance of families from the South Fork was also evident after 16 years of field testing at four locations (Rehfeldt 1980).

PRACTICAL APPLICATION

Systematic patterns of genetic variation have developed from the action of natural selection in synchronizing developmental events with the local climate. Consequently, the patterns are directly applicable to artificial reforestation. Planted trees must be adapted to the planting site if productivity is to be maximal. Adaptation is secured by limiting the distance that seeds are transferred from their origin. Consequently, limits to seed transfer must reflect geographic and elevational patterns of variation.

One way of controlling maladaptation is to construct discrete seed zones, the boundaries of which are determined by the smallest geographic and elevational intervals across which differentiation can be detected (Rehfeldt 1979a). Differentiation along the elevational cline (figs. 2 and 3) suggests that a seed zone for ponderosa pine should not encompass more than 1,300 feet of elevation. This means that seed from a single source should not be transferred more than ±650 feet elevationally. In addition, the geographic clines of figure 4 describe seed zones that should not encompass more than two of the geographic bands between isopleths. Thus, approximately three geographic zones would be suitable for the region, and seeds from a single source should not be transferred a distance equivalent to more than ±1 band. These elevational and geographic restrictions jointly delineate six seed zones for the ponderosa pine forests of central Idaho.

Discrete seed zones, however, compartmentalize continuous genetic variation and, thereby, tend to be inflexible, inefficient, and uneconomical. An alternative procedure involves constructing floating transfer guidelines that are based on the recurrence of similar genotypes at different elevations in geographically separated localities. According to floating guidelines, seed can be transferred across isopleths (fig. 4), but each time seed is transferred across a geographic interval equaling the interval between isopleths, the elevations at which the seed is to be used should be adjusted. When transferring across isopleths of high to low value, the interval should be adjusted downward by 650 feet; when transferring from lower to higher value, the interval should be adjusted upward by 650 feet.

Two examples:

1. Assume that seed originates from 5,000 feet anywhere along the isopleth representing the mean of all populations (fig. 4). This seed should be used between 4,350 and 5,650 feet in lands adjacent to the contour. In transferring the seed across one isopleth of larger value, the seed should be used between 5,000 and 6,300 feet. In transferring the seed across an isopleth of lesser value, the seed should be used between 3,700 and 5,000 feet. And transfers across two contours of lesser value should be used between 3,050 and 4,350 feet.

2. By recognizing that the guidelines are based on equivalent performance, floating transfer guides can be constructed from the elevational clines of figure 2. Thus, seed collected from 5,000 feet at Idaho City (locality C) can be used at 4,100 ± 650 feet at Lowman (D), at 4,440 ± 650 feet at New Meadows (G), at 5,200 ± 650 feet at Council (B), and at 6,000 ± 650 feet in the South Fork (H). In these ways, seed from a single source or seed orchard can serve a much broader geographic area than under the concept of discrete seed zones.

Populations from the South Fork may offer unique possibilities to forest management. These populations express a growth potential that is typical of populations adapted to mild environments while maintaining an adaptedness that is typical of populations adapted to severe environments. This suggests that in severe environments productivity might be increased by importing foreign populations. But additional research and operational assessments must be completed before general guidelines can be developed for using these seeds.

These recommendations for limiting seed transfer evolved from statistical models based on the performance of young trees under controlled conditions. On the one hand, the environmental events responsible for the systematic patterns may occur so infrequently that managers might risk transferring fast-growing populations into severe environments in an attempt to increase productivity. Indeed, genetic differentiation may have been detected at levels associated with productive differences so small as to be immaterial. But, on the other hand, small adaptive differences observed at young ages may accumulate and thereby portend large differences in the future. As Dietrichson (1964) has shown, many of these accumulated effects involve insects and diseases. Consequently, the models need practical verification. Verification can come only from planting programs that not only incorporate these guidelines but also maintain precise records on the exact location from which planted trees originated. Productivity of such plantings will test the applicability of these guidelines.

REFERENCES

Dietrichson, J. 1964. The selection problem and growth rhythm. Silvae Genetica. 13: 178-184.

Draper, N. R.; Smith, H. 1981. Applied regression analyses. New York: Wiley and Sons. 407 p.

Madsen, J. L.; Blake, G. M. 1977. Ecological genetics of ponderosa pine in the northern Rocky Mountains. Silvae Genetica. 26: 1-8.

Rehfeldt, G. E. 1979a. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var *glauca*) populations. I. North Idaho and northeast Washington. Heredity. 43: 383-397.

Rehfeldt, G. E. 1979b. Genetic variation in southern Idaho progeny tests after 11 years. Gen. Tech. Rep. INT-75. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Rehfeldt, G. E. 1980. Genetic gains from tree improvement of ponderosa pine in southern Idaho. Res. Pap. INT-236. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Rehfeldt, G. E. 1986a. Adaptive variation in *Pinus ponderosa* from Intermountain Regions. I. Snake and Salmon River Basins. Forest Science. 32: 79-92.

Rehfeldt, G. E. 1986b. Adaptive variation in *Pinus ponderosa* from Intermountain Regions. II. Middle Columbia River System. Res. Pap. INT-373. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 9 p.

SAS Institute. 1982. SAS user's guide. Vol. 2. Cary, NC: SAS Institute. 584 p.

Steel, R. G. D.; Torrie, J. H. 1960. Principles and procedures of statistics. New York: McGraw-Hill. 481 p.

Steele, R.; Pfister, R. D.; Ryker, R. A.; Kittams, J. A. 1981. Forest habitats of central Idaho. Gen. Tech. Rep. INT-114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 138 p.

APPENDIX: LOCATION AND PERFORMANCE OF POPULATIONS

Collection number	Location	Latitude	Longitude	Elevation	Height	Duration	Rate
		- - - - Degrees	- - - -	Meters	cm	Days	cm/day
1	Panther Creek	44.95	114.33	1829	32.4	27.46	2.74
2	Sheep Creek	45.50	113.92	1341	36.3	33.66	4.34
3	Bald Mountain	45.50	114.17	1875	32.3	30.32	3.45
4	Squaw Creek	45.50	114.22	1743	36.7	26.93	3.64
5	Papoose Creek	45.45	114.22	1646	38.7	32.40	3.95
6	Lower Papoose	45.42	114.18	1426	45.4	32.49	3.56
7	Warm Spring Ridge	43.85	115.88	1433	40.1	32.88	3.75
8	Sagehen	44.32	116.23	1585	39.5	32.70	3.86
9	Third Fork	44.37	116.33	1158	43.0	30.52	3.63
10	Powelson Creek	44.78	115.87	1829	39.9	30.35	3.48
11	Bear Creek	43.95	115.47	1829	38.1	30.17	3.40
12	South Fork of Payette	44.07	115.50	1280	44.7	30.18	4.10
13	Mill Creek	44.67	116.87	1250	43.4	33.81	4.04
14	Rabbit Creek	43.80	115.72	1829	41.9	31.15	4.04
15	Mud Creek	45.05	116.38	1341	43.3	31.99	4.16
16	Rough Creek	44.90	116.48	1128	40.8	32.15	3.98
17	Circle Creek	45.05	116.27	1280	42.4	32.25	3.79
18	Three Mile	44.98	116.22	1341	46.1	31.85	3.78
19	Dutch Creek B	43.73	115.45	1676	41.7	31.19	3.79
20	Trail Creek	43.60	115.75	1341	48.1	35.83	4.13
21	West Fork Creek	44.30	115.87	1219	38.5	32.83	4.11
22	Garden Valley	44.07	115.93	945	42.9	31.66	3.75
23	Dutch Creek A	43.80	115.37	1402	39.6	30.25	3.86
24	Camp Creek	44.88	115.70	1311	46.6	30.75	3.78
25	Zena Creek	45.68	115.75	1463	43.3	29.58	4.20
26	Wagon Town A	43.62	115.28	1768	34.7	30.12	3.48
27	Wagon Town B	43.62	115.18	1707	38.5	31.45	3.79
28	Wagon Town C	43.62	115.72	1798	42.5	32.72	3.57
29	Elk Creek	43.62	115.72	1311	46.6	34.67	3.61
30	Long Gulch	43.62	115.62	1463	43.6	30.46	3.98
31	Bear Run	43.83	115.83	1341	42.7	33.75	3.47
32	Humbug	43.83	115.72	1250	44.2	32.54	3.79
33	Clay Creek SPA	43.95	115.83	1341	40.8	33.21	3.93
34	Dutch Creek II	43.83	115.28	1341	36.7	30.98	3.60
35	Weatherby Flats	43.83	115.28	1402	45.1	34.20	3.69
36	Canyon Creek	44.22	115.18	1554	38.7	30.99	4.08
37	Ten Mile Creek	44.12	115.28	1341	41.8	32.70	3.76
38	Logging Gulch	44.12	115.62	1250	45.6	32.62	3.96
39	Dry Buck	44.12	116.17	1524	43.4	32.99	4.40
40	Second Fork of Squaw Creek	44.37	116.17	1402	42.7	33.50	3.92
41	Wash Creek	44.05	115.83	1158	44.6	33.53	3.79
42	Bell Creek	44.22	115.83	1036	46.5	35.78	3.65
43	Carpenter Creek	44.12	115.83	1494	40.0	31.43	4.30
44	Crawford Creek II	44.53	115.95	1554	37.6	31.89	3.71
45	Skunk Creek	44.37	115.95	1585	38.6	30.67	3.34
46	Crooked River SPA[1]	44.83	116.67	1402	40.4	30.87	3.07
47	Calamity SPA	44.70	116.67	1768	45.1	30.40	3.97
48	Bear Gulch	44.97	116.42	1646	38.9	29.93	3.93
49	Slaughter Gulch	44.97	116.42	1554	40.5	29.72	3.98
50	Shingle Flat	44.80	116.28	1433	41.3	33.26	3.73
51	Mill Creek Basin	44.70	116.28	1524	46.2	33.84	4.13
52	Tamarack Creek	44.62	116.80	1372	46.5	34.71	4.42
54	Pony Creek	45.25	115.62	1859	40.9	28.22	3.77
55	Barker Gulch II	43.17	115.18	1433	38.2	32.82	3.87
56	Abbot Gulch	43.17	115.18	1402	37.7	29.47	3.11
57	Pine Gulch	43.17	115.18	1524	43.3	30.34	3.65
58	Gardner Gulch	43.17	115.00	1524	41.5	29.37	3.97
59	Grouse Gulch SPA	43.50	113.92	1524	40.9	32.62	3.43
60	Lost Creek	44.83	116.42	1158	42.9	33.75	3.90
61	Frog Pond	44.80	116.28	1067	41.2	30.91	4.02
62	Burnt Basin	44.62	116.17	1615	41.9	33.68	3.76
63	Hot Springs Creek	45.32	114.33	1707	37.6	32.13	4.02
64	Vine Creek	45.63	114.00	1707	39.8	31.70	3.67
65	Silverleads	45.45	113.97	1798	39.6	30.83	3.82

---

[1] Seed production area.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

October 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-374

A Simple Method for Computing Spotting Distances From Wind-Driven Surface Fires

Glen A. Morris[1]

ABSTRACT

Summarizes past efforts to model fire spotting from wildland fires. Explains how Albini's spotting model for wind-driven surfaces was simplified with no loss in accuracy and the resulting model implemented in the BEHAVE fire prediction and fire modeling computer system and on the HP-71B calculator.

KEYWORDS: wildland fires, fire behavior, fire modeling, fire physics, fire management, spotting, firebrand

A mathematical model has been developed (Albini 1979, 1981, 1983) to predict maximum distances spot fires will be ignited by and ahead of wildland surface fires. The firebrand sources treated are:

1. Torching trees,
2. Burning piles, and
3. Wind-driven surface fires.

This note describes the nature of spotting from wind-driven surface fires as it affects practical fire behavior modeling. It describes how Albini's spotting model (Albini 1979, 1981, 1983) was simplified without adverse effect on accuracy. The simplified model has been implemented in the BEHAVE fire prediction and fuel modeling computer system (Andrews and Chase in preparation), and on the Hewlett-Packard HP-71B calculator[2] (Susott and Burgan 1986). Part of this note describes these implementations.

SPOTTING MODEL

Albini's spotting model provides that, regardless of the source, all firebrand trajectories are similar except for the first phase of the trajectory in which the lofting height (initial firebrand height) is attained. Calculation of lofting height for torching trees or burning piles is now a simple matter. In order to implement the simplified method for calculating lofting heights from wind-driven surface fires, Albini began with a complex approach. Fireline intensity pulses that cast firebrands aloft were modeled by means of a best-fit frequency spectrum. This computation-intensive model, known as the spectral model, estimates the energy in a typical pulse (the thermal energy).

Albini then proposed a simpler model, called the "lofting energy model" (Albini 1983), which is derived from the spectral model. The lofting energy model requires two parameters to be derived by exercising the spectral model. The two parameters are fuel dependent and must be computed for each condition of fuel type and moisture.

The lofting energy model estimates mean thermal energy per foot of fireline (E) at the front of wind-driven surface fires spreading at a uniform rate under good burning conditions:

$$E = IA(0.474U)^B \text{ (btu/ft)} \tag{1}$$

I = fireline intensity (btu/ft/s)
U = windspeed at 20 ft (mi/h)
A = the fuel-dependent time parameter (s)
B = the fuel-dependent shape parameter

or in power-law form:

$$E/I = A(0.474U)^B \text{ (s)} \tag{2}$$

Each fuel condition specifies a different pair of values for A and B.

The following section recounts how A and B were obtained for each fuel model. The paper then deals with the sensitivities involved and shows how further simplification was achieved.

---

[1] Mathematician, located at Intermountain Station's Intermountain Fire Sciences Laboratory, Missoula, MT.

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

CALCULATING THE FUEL-DEPENDENT PARAMETERS

For each of the 13 fire behavior fuel models (Anderson 1982), seven moisture levels and six windspeeds were chosen. For each combination of fuel, moisture, and windspeed (U), the following was done:

1. Rate of spread (R) and Byram's fireline intensity (I) were obtained using the BEHAVE fire behavior processor (Andrews and others in preparation).
2. Thermal energy was computed using Albini's spectral model, with R and I as inputs (Albini 1982b). Appendix A describes this calculation in detail.

This provided a value of thermal energy for each of the six windspeeds for each fuel and moisture combination.

As long as the 20-ft windspeed does not go below 4.2 mi/h, with few exceptions, a close and meaningful curve fit is obtained that provides reasonable values for A and B. Once the log linear least squares curve has been fitted, the pair (A,B) should reflect the fuel conditions; that is, the particular power-law will look different when plotted for each fuel type or moisture level. This entire process is performed by the computer program ABGEN (on file at the Intermountain Fire Sciences Laboratory), which is based on procedures explained by Albini (1982a, 1982b, 1983).

Albini had independently performed the calculation of the two fuel-dependent parameters for each of 12 of the standard fuel models (Albini 1983). Analysis of his A and B parameters revealed an error in earlier work. A correction to tables 3 and 4 of the cited publication was published in Chase (1984).

SENSITIVITIES OF MAXIMUM SPOTTING DISTANCE

The parameters A and B were determined for the 91 combinations of fuel model and moisture level mentioned above. From the extreme values in this array of parameters, I was able to demonstrate the effect of A and B on maximum spotting distance and found that the influence of both fuel type and moisture level upon the maximum distance is largely accounted for by their effect on fireline intensity.

Appendix B treats this matter in some detail. By argument and calculation, it shows that moisture impacts the maximum distance only indirectly through the fireline intensity. So, for the purpose of demonstrating the direct impact of fuel model on maximum spotting distance, the moisture level did not have to be precisely determined. In each case a low value was chosen but care was taken to avoid values beyond the capability of the fire model (Rothermel 1972). The levels chosen ranged from 3 to 8 percent.

Table 1 lists the coefficients by fuel model. For each model we have an (A,B)-pair characterizing the power-law response of E/I to windspeed. As A increases, the curve steepens and lofting becomes efficient, especially at low 20-ft windspeeds (5 mi/h is considered low for spotting). From table 1 it would appear that fuel type is important.

Table 1—Ranked listing of the fuel-dependent parameters for computing the energy (E) in a typical fireline thermal. Knowing the mean fireline intensity (I) and the 20-ft mean windspeed (U), one estimates the thermal energy as

$$E = IA(0.474U)^B \text{ (btu/ft)}$$

These values agree with Chase (1984), a corrected version of those originally published in Albini (1983)

	Fire behavior fuel model	A (s)	B
9	Hardwood litter	1,121	- 1.51
2	Grassy understory	709	- 1.32
1	Short grass	545	- 1.21
3	Tall grass	429	- 1.19
4	Mature chaparral	301	- 1.05
8	Conifer litter	262	- .97
6	Dormant brush	242	- .94
5	Young chaparral	235	- .92
10	Overgrown slash	224	- .89
7	Southern rough	199	- .83
11	Light conifer slash	179	- .81
13	Heavy conifer slash	170	- .79
12	Medium conifer slash	163	- .78

Fire-pulse energies tend to increase more in response to decreasing wind for some fuels than for others. Even so, the condition that favors stronger vertical pulses is the condition that shortens horizontal travel of firebrands.

Consequently, we would expect that spotting distance is not highly sensitive to either A or B. Figure 1 confirms this, showing that the maximum distance is primarily a function of fireline intensity and windspeed. Obtained by exercising the spotting model, it shows that the direct effect of fuel type on maximum distance is considerably less than that of windspeed or fireline intensity. Even if two fuel models are drastically different, their effects on maximum distance differ by roughly 20 percent. If we were to use a single (A,B)-pair to represent all fuel models, the maximum error is conservatively about 10 percent—readily acceptable for the simplification provided.

Because variations in A and B have relatively little effect on the maximum distance traveled, one pair of values will suffice for all the standard models. In addition, there is no reason to believe that custom fuel models (Burgan and Rothermel 1984) will call for coefficients that vary more than those encountered; consequently, both standard and custom fuel models are represented by a single (A,B)-pair. The logical choice for these values was the averages of the parameters listed in table 1. Averaging the A and B values in the table and using the averaged coefficients in equation (1), we have

$$E = 322I(0.474U)^{-1.01} \cong 322I/(0.474U) \text{ (btu/ft)} \qquad (3)$$

which encompasses all fuel conditions for estimating maximum spot-distance. This equation is implemented in BEHAVE. (A and B values for all 13 fire behavior fuel models were computed and included in the averaging, even though the model for spotting from wind-driven surface fires is not applicable under significant canopy cover.)

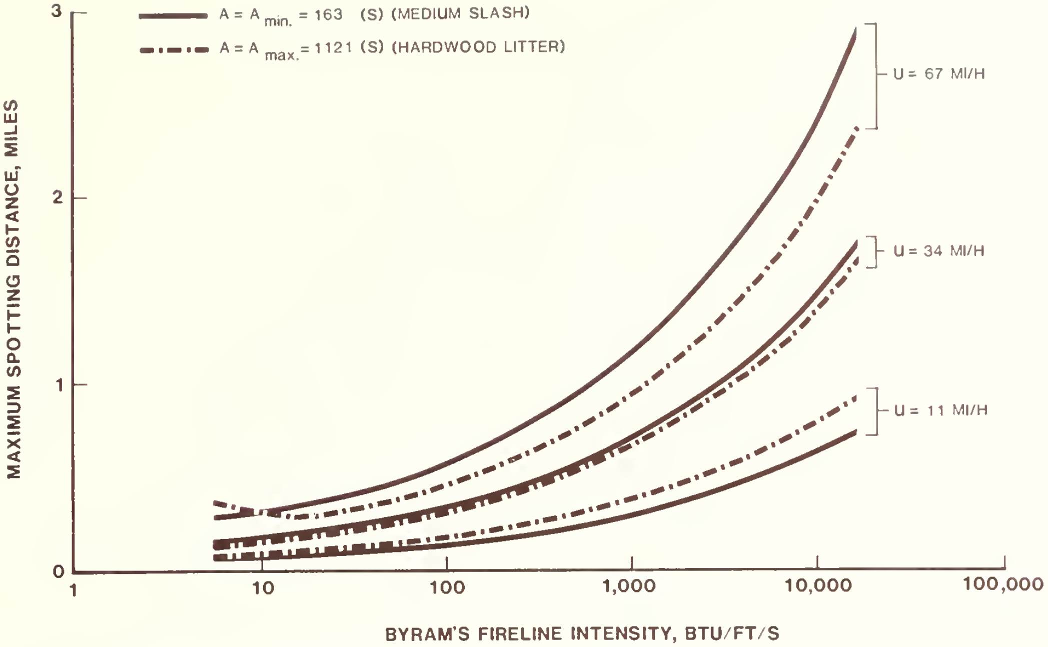


Figure 1—Sensitivities of maximum spotting distance to mean fireline intensity, mean 20-ft windspeed (U), and fuel model.

HREE-GROUP IMPLEMENTATION IN HE HP-71B

At the time the wind-driven surface spotting model was eing implemented on the HP-71B (Susott and Burgan 986), the simplification of thermal strength calculations ad not been completed; consequently, the HP-71B version s not a simple use of equation 3. The standard fuel odels were divided into three broad groups and one set f parameters (within-group averages of A and of B) ssigned to each group (see table 2). A simple classification cheme was devised to decide which of three (A,B)-pairs hould be assigned to a custom fuel model.

Based on the assumption that fuel that burns well should roduce energetic fireline pulses, Wilson's (1985) fuel-urface-area to fuel-bed-area ratio (S) was used to classify uel models:

$$S = \sigma\beta\delta = \sigma w_0/\rho \qquad (7)$$

here

σ = surface-to-volume ratio (ft^{-1})
β = packing ratio
δ = fuel depth (ft)
w_0 = fuel loading (lb/ft^2)
ρ = bulk density (lb/ft^3)

t was found that S provides an adequate "discriminator" or classifying fuel models into the three groups.

Just as fuel model parameters (loading, etc.) are stated or dead or live fuel by size class, S can also be expressed his way. The components of S used are:

S_1 = S for dead 1-hour fuel
S_{10} = S for dead 10-hour fuel
S_{100} = S for dead 100-hour fuel
S_H = S for live herbaceous fuel.

Table 2—Grouping of the fuel-dependent parameters used in the equation

$$E = IA(0.474U)^B \text{ (btu/ft)}$$

To estimate the typical thermal energy (E) of a fireline, one needs to know (1) the mean fireline intensity (I), (2) the 20-ft mean windspeed (U), and (3) the classification (group number, n). The three groups correspond to the three-group implementation of the spotting model implemented on the HP-71B calculator

	Fuel model	A (s)	B	Group n	A	B
9	Hardwood litter	1,121	−1.51	1	560	−1.25
2	Grassy understory	709	−1.32			
1	Short grass	545	−1.21			
3	Tall grass	429	−1.19			
4	Mature chaparral	301	−1.05	2	240	−.95
8	Conifer litter	262	−.97			
6	Dormant brush	242	−.94			
5	Young chaparral	235	−.92			
10	Overgrown slash	224	−.89			
7	Southern rough	199	−.83			
11	Light conifer slash	179	−.81	3	170	−.80
13	Heavy conifer slash	170	−.79			
12	Medium conifer slash	163	−.78			

Table 3—Ratios of fuel surface area to fuel bed area (S) for standard fuel models

Fire behavior fuel model	S_1 1-h	S_{10} 10-h	S_{100} 100-h	S_w Live herbaceous	S_H Live woody
1	3.7	0	0	0	0
2	8.6	0.2	0.02	1.1	0
3	6.5	0	0	0	0
9	10.5	.1	.01	0	0
11	3.2	.7	.2	0	0
12	8.6	2.2	.7	0	0
13	15	3.6	1.2	0	0
4	14	.6	.1	0	11
5	2.9	.1	0	0	43
6	3.8	.4	.1	0	0
7	2.8	.3	.1	0	.8
8	4.3	.2	.1	0	0
10	8.6	.3	.2	0	4.3

Table 3 gives the value for each of these components in the 13 fire behavior fuel models. A dynamic fuel model would adjust S_1 and S_H to simulate the curing of live fuel through the season (Andrews and others in preparation).

By inspection of data such as table 3, the following rule was devised for classifying a given fuel model. The group number n is set between 1 and 3, according to the following rules.

$$n = \begin{cases} 1 \text{ if } S_{100} \text{ does not exceed } 0.05,\ S_H \text{ does not exceed } 2, \text{ and } S_{10} \text{ is less than } 0.5 \\ 3 \text{ if } S_{100} \text{ exceeds } 0.05,\ S_H \text{ does not exceed } 2, \text{ and } S_{10} \text{ is not less than } 0.5 \\ 2 \text{ otherwise} \end{cases}$$

In descriptive terms, a fuel model is likely to belong to group 1 if it is very light (grass, etc.), to group 3 if rather heavy, as is slash, and to group 2 if between these extremes.

Once the fuel model is classified, a reasonable (A,B)-pair can be assigned to it as shown in table 2. The fuel models in Group 1 have large A-parameters; the power-law for these fuel models is steep, and lofting efficiency sensitive to windspeed. Heavy slash, on the other hand, sure to fall into group 3, will be assigned an (A,B)-pair representing insensitivity of lofting efficiency to windspeed.

Testing of this algorithm has been meager. It correctly classified three custom fuel models known to belong to group 3 and one known to belong to group 2, and it classifies the 13 fire behavior fuel models correctly. The scheme has been adopted on these empirical grounds and implemented on the HP-71B calculator.

As far as maximum spotting distance is concerned, it makes little difference whether the three-group version is used or the BEHAVE version (equation 3).

RECOMMENDATIONS

Further testing is recommended. In addition, further research should address the question: how often is maximum distance attained? Because frequency of thermals is now calculated in the simplified model, part of the answer is at hand. But to fully answer the question we must also consider the effect of firebrand size.

REFERENCES

Albini, F. A. 1979. Spot fire distance from burning trees—a predictive model. Gen. Tech. Rep. INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 73 p.

Albini, F. A. 1981. Spot fire distance from isolated sources—extensions of a predictive model. Res. Note INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 9 p.

Albini, F. A. 1982a. Response of free-burning fires to nonsteady wind. Combustion Science and Technology. 29: 225-241.

Albini, F. A. 1982b. The variability of wind-aided free-burning fires. Combustion Science and Technology. 31: 303-311.

Albini, Frank A. 1983. Potential spotting distance from wind-driven surface fires. Res. Pap. INT-309. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 27 p.

Anderson, Hal E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Andrews, P. L.; Chase, C. H. [In preparation]. BEHAVE: fire behavior prediction and fuel modeling system—BURN subsystem, part 2. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Andrews, P. L.; Chase, C. A.; Morris, G. A. [In preparation]. Equations for wildland fire behavior: a summary. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Burgan, R. E.; Rothermel, R. C. 1984. BEHAVE: fire behavior prediction and fuel modeling system—FUEL subsystem. Gen. Tech. Rep. INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 126 p.

Chase, C. H. 1984. Spotting distance from wind-driven surface fires—extensions of equations for pocket calculators. Res. Note INT-346. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 21 p.

Rothermel, Richard D. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.

Susott, Ronald A.; Burgan, Robert E. 1986. Fire behavior computations with the Hewlett-Packard HP-71B calculator. Gen. Tech. Rep. INT-202. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 80 p.

Wilson, Ralph A., Jr. 1985. Observations of extinction and marginal burning states in free-burning porous fuel beds. Combustion Science and Technology. 44: 179-193.

APPENDIX A: USING THE SPECTRAL MODEL

Each value of thermal energy (E) is obtained by the following three-step process, which evaluates the spectral equations (Albini 1982b). For a given fuel-type, moisture evel, and mean 20-ft windspeed, the following is done:

1. Calculate Albini's frequency sprectrum (S_I) for wind-driven fireline intensity variations. This is a spectral density function.
2. Locate the frequency ($W_{\max}$) of maximum spectral density ($S_{\max}$) and integrate S_I to get the variance (σ^2) for the intensity variations.
3. Find a random-interval pulse train consisting of rectangular alternating pulses that matches certain features of the spectrum S_I. This is done by specifying the pulse amplitude (A'), period (T), and frequency of occurrence (P_{on}):

$$T = 0.742(2\pi/W_{\max}) \tag{4}$$

$$A' = \sigma/P_{\text{on}} \tag{5}$$

The value of P_{on} is chosen so as to match the pulse-train spectral peak to $S_{\max}/(\sigma^2/T)$. Under good burning conditions, a wind-driven surface fire will often pulse and have an observable mean pulse rate and, also, a typical amount of energy (E) per pulse. This says that a typical value for E should exist for each condition. This is the basis for trying to match a single-rate constant-amplitude pulse train. The typical thermal energy should be the pulse-train's pulse energy:

$$E = A'T/2 \text{ (btu/ft)} \tag{6}$$

Steps 1, 2, and 3 and the evaluation of equation 6 were performed for the six windspeeds for each of the 91 curve fits mentioned.

APPENDIX B: EFFECT OF FUEL TYPE AND MOISTURE ON MAXIMUM SPOT-DISTANCE

Albini provided a mathematical proof (on file at the Intermountain Fire Sciences Laboratory) that most of the variation in thermal energy (E) is due to fireline intensity. The proof consists in showing that E is roughly proportional to $I\,R_o^{-1/2}$. We write

$E \propto I\,R_o^{-1/2}$, where

R_o = rate of spread at zero windspeed.

We might prove this by considering the frequency response of normalized fireline intensity variations ($\Delta I/I$) (Albini 1982b). The response increases more or less linearly up to some cutoff frequency (w_c) above which the spectral lobes are relatively small. The cutoff is well below the peak frequency of the wind spectrum. The wind spectrum increases up to w_c; therefore, w_c will be the lowest peak-frequency for the wind-driven intensity spectrum. Now this spectrum is for the normalized intensity variations so we have as variance $(\sigma/I)^2$. We expect that

$$(\sigma/I)^2 \propto w_c$$

because of the approximate linearity of the final spectrum up to w_c.

Using a random-interval repeated square wave to represent fireline intensity pulses, Albini (1983) has us match the wave to fuel-dependent spectra by matching the pulse period (T) and amplitude (A'):

$$T \propto 1/w_c$$

$$P_{\text{on}}A'A' = \sigma^2$$

where

P_{on} is insensitive to w_c.

Consequently,

$$A' \propto \sigma \propto I\sqrt{w_c}$$

and

$$A'T \propto I/\sqrt{w_c}$$

and

$$E = A'T/2 \propto I/\sqrt{w_c}$$

But as Albini shows

$$w_c \cong 2\pi R_o/\delta$$

where

δ = fuel depth.

Consequently,

$$E \propto I\,R_o^{-1/2}$$

Thus, the particle-lofting energy depends on fuel conditions only indirectly, and that effect is accommodated by the fireline intensity.

Now this argument does not convince the author; however, figure 2 is further confirmation that, in most cases, fuel moisture is not important for calculating maximum spotting distance. Most of the curves are nearly flat, the exceptions being cases where the intensity frequency spectrum is poorly represented by any square pulse train. These exceptional cases seem to imply considerable sensitivity of *A* (and *B*) to moisture; however, it turns out that these coefficients have little control over maximum spotting distance (see fig. 1).

We have, then, both a heuristic argument and a numerical demonstration that the effect of fuel type and moisture on maximum spot distance is, in practical terms, accounted for by the mean fireline intensity.

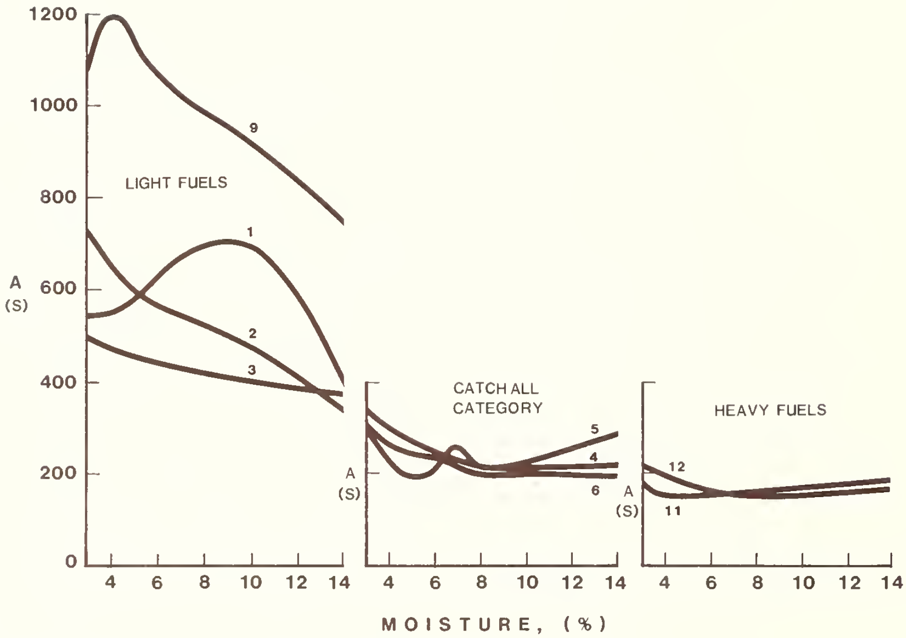


Figure 2—Response of particle lofting tendency, as reflected by the power-law coefficient *A*, to dead fuel moisture level. Note: The three fuel type groups are plotted separately, the numbers indicating fuel model number (see table 2). Models 7, 10, and 13 are omitted because they differ little from others in their group.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

October 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

ted States
partment of
riculture

est Service

ermountain
search Station

search Note
-375

Susceptibility of Inland Douglas-fir to *Rhabdocline* Needle Cast

Ray J. Hoff[1]

BSTRACT

hree family tests of Douglas-fir were scored for degree needle damage caused by the needle cast fungus Rhabdline pseudotsuga. *Genetic variability was moderate. mily heritabilities were 34, 36, and 66. Heritabilties ed upon individuals were 22, 28, and 41. Data could be d in Christmas tree or forest improvement programs.*

YWORDS: tree breeding, disease resistance, *Pseudotsuga menziesii*

n 1984 three family tests of Douglas-fir (*Pseudotsuga nziesii* var. *glauca* [Beissn.] Franco) were planted by sonnel of the Northern Region of the Forest Service at Dry Creek tree improvement site. The site is 32 miles t of Sandpoint, ID, at 48°04′ N. latitude, 116°09′ W. gitude at an elevation of 2,400 ft.

n April 1986 a needle cast became apparent. The causal gus was identified as *Rhabdocline pseudotsugae* Syd. by James, Forest Pest Management, Northern Region, ssoula, MT. In April infection appeared light, but by l-May it was obvious that infection was severe.

rovenances from the northern portion of the inland iety (Idaho-Montana) of Douglas-fir are known to be derately susceptible to this needle cast while those of coastal variety (*P. menziesii* var. *menziesii* [Mirb.] anco) are highly resistant and those from the southern ge of the inland variety (*P. menziesii* var. *glauca*) are hly susceptible (Stephan 1973, 1980).

he fungus is native to North America and was first scribed from collections from Montana and Idaho (Weir 17). It has since been found wherever Douglas-fir is wn and is a major problem in young plantations orton and Miller 1977). The fungus infects both sides of leaves during cool (50 °F) and moist (near 100 percent humidity) periods of at least 3 days duration during the time of first flush in early summer (Stephan 1973). Infection occurs by direct penetration of the cuticle (Brandt 1960). Initial symptoms are seen as slight yellow spots on the needle surface in early winter. By early spring the spots have changed to yellowish brown. The combination of healthy green tissue with the yellowish-brown spots cause much of the infected surface to appear mottled. In late spring and early summer the spots become red brown, apothecia form, spores are liberated, and casting of the most severely damaged needles begins.

The Dry Creek test comprised many families of Douglas-fir planted in 24-tree family plots, thus making it obvious that there were major differences among the families. This paper documents the genetic variation among these families.

MATERIALS AND METHODS

The inland population of Douglas-fir has been divided into several "breeding zones" for the purpose of testing and selection of fast growing trees. These breeding zones were derived from data provided by Rehfeldt (1979, 1982) on adaptive variation. In Idaho each breeding zone comprises two degrees of latitude and 1,000 ft of elevation.

The seedlings planted at Dry Creek were from selected "plus" trees from three elevation zones between latitude 45°22′ N and 47°8′ N in Idaho. These zones are designated as low, mid, and high and represent the three breeding zones at the range of latitude listed above. Zone low had 195 families, mid had 219 families, and high had 186 families. The seedlings were derived from open-pollinated seed with seed from individual trees assumed to be half-sibs. The seeds were sown in containers at the Forest Service Nursery, Coeur d'Alene, ID, during spring 1983 and planted at the Dry Creek site during spring 1984.

The experiment consisted of a randomized complete block design, with two blocks, 24 seedlings per block, and family plots. Seedlings were spaced at 3 by 3 ft, and seedlings of the three elevation zones were planted in separate but adjacent tests.

---

[1] rincipal plant geneticist located at Intermountain Research Station's estry Sciences Laboratory, Moscow, ID.

When the needle cast was at its maximum visibility, the last week of May 1986, each seedling was rated according to the classification:

0 = no needle damage
1 = <25 percent of the needle area damaged by needle cast
2 = 26 to 50 percent of the needle area damaged
3 = 51 to 75 percent of the needle area damaged
4 = >75 percent of the needle area damaged

Family means and analysis of variance were completed using the mean of the class: 0 = 0; 1 = 13 percent; 2 = 38 percent; 3 = 64 percent; and 4 = 88 percent. The model of the analysis of variance is shown in table 1.

Table 1—Model for the analysis of variance and expected mean squares for the damage caused by *Rhabdocline pseudotsugae* to Douglas-fir

Source	Degrees of freedom	Expected mean squares
Block	b-1[1]	$\sigma_W^2 + k\sigma_{BF}^2 + fk\sigma_B^2$
Families	f-1	$\sigma_W^2 + k\sigma_{BF}^2 + bk\sigma_F^2$
Block × families	(b-1)(f-1)	$\sigma_W^2 + k\sigma_{BF}^2$
Within	bf(k-1)	σ_W^2

[1] b = number of blocks,
f = number of families,
k = number of seedlings per plot; because the number of individuals within plots varied, k represents the harmonic mean.

RESULTS

The distribution of damage classes over all seedlings shown in table 2. The average amount of foliage that w damaged for elevation zone low was 41 percent, for mi 53 percent, and for high 52 percent (table 3).

The among-family differences for all three elevation zones were highly significant (table 4). The block × fan effect was also significant, indicating a substantial diffe ence in the level of infection in individual families withi each of the two blocks.

Table 2—Frequency of *Rhabdocline pseudotsugae* damage classes for three populations of Douglas-fir

	Damage classes					
Test	0	1	2	3	4	T
	Percent					*Nu*
Low	2	24	38	33	3	8,
Mid	1	6	28	62	3	9,
High	0	9	29	60	2	8,

Table 3—*Rhabdocline pseudotsugae* damage on three elevati zones of Douglas-fir at Dry Creek

		Damage	
Elevation zone	Families	Mean	R
	Number	*Percent*	
Low	195	41	1
Mid	219	53	2
High	186	52	3

Table 4—Analysis of variance of *Rhabdocline pseudotsugae* damage for three elevation zon Douglas-fir at Dry Creek

	Low		Mid		High	
Source	df	MS	df	MS	df	
Block	1	4.232	1	1.633	1	2.2
Family	194	.369**	218	.182**	185	.2*
Block × family	194	.232**	218	.118**	185	.0*
Within	7,937	.034	9,376	.023	802	.0

**denotes significant difference at the 1 percent level of probability.

Table 5—Variance components, percent of variation, and heritabilities of the damage by *Rhabdocline pseudotsugae* for three elevation zones of Douglas-fir at Dry Creek

	Elevation zone					
	Low		Mid		High	
Source	Variance components	Percent variation h^2	Variance components	Percent variation h^2	Variance components	Percent variation h^2
Block	0.001	2	0.0003	1	0.0005	2
Families	.003	6	.002	7	.003	10
Block × family	.010	21	.004	14	.002	7
Within	.034	71	.023	78	.024	81
Family		34		36		66
Individual		26		28		41

The variance components, percent of variation, and heritabilities are shown in table 5. Harmonic means of individuals within plots were 20.8 for low, 22.1 for mid, and 22.2 for high.

DISCUSSION

Several Douglas-fir families had a fairly high level of resistance to *Rhabdocline* needle cast, while others were highly susceptible. Although the three tests could not be statistically compared, the test areas were adjacent and could be compared assuming the whole site was homogeneous. This assumption is probably reasonable because all three tests take up less than 6 acres. The families with the highest resistance were from the low elevation zone. Mid and high elevation families were about the same. This agrees with reports on other provenance tests (Mortant and Zhu 1986) and agrees with observations that this disease is most prevalent at lower elevation in this area. This is perhaps because by the time high-elevation trees begin growth and are the most susceptible, the weather typically has become hot and dry and not conducive to *Rhabdocline* infection.

Heritabilities were moderate. A selection at one unit of *i* of the most resistant individuals would yield a gain of 21, 15, and 31 percent for the low, mid, and high zones, respectively. And likewise, the same intensity of selection for families would provide a gain of 61, 43, and 47 percent for these zones.

The impact of *Rhabdocline* needle cast is not noticeable in pole-sized and older stands because tree mortality is not common. However, Kurkela (1981) reported a decrease both in height and radial increment as severity of infection increased. Also, the impact is long lasting. Slightly infected dominant trees recovered within a few years, but more severely infected ones took 10 years or more. Seriously infected codominant and suppressed trees did not recover.

Christmas tree plantations are especially vulnerable because they are planted in closely spaced, highly susceptible monocultures and because there is no rotation of species. Morton and Miller (1977) reported that 71 percent of the trees in one plantation site were unmerchantable. In another plantation, 51 percent of the trees had only a 1-year complement of needles.

Christmas tree growers could benefit by selecting for *Rhabdocline* resistance. For forest plantings, resistance in areas of high hazard should be increased, especially if the impact can be shown to be high in these areas. In less hazardous sites, maintenance of genetic variability of natural resistance would suffice.

REFERENCES

Brandt, R. W. 1960. The *Rhabdocline* needle cast of Douglas-fir. Tech. Publ. 84 Syracuse, NY: State University College of Forestry at Syracuse University. 66 p.

Kurkela, T. 1981. Growth reduction in Douglas-fir caused by *Rhabdocline* needle cast. Communicationes Instituti Forestalis Fenniae No. 102. Helsinki, Finland: Finnish Forest Research Institute. 16 p.

Morton, H. L.; Miller, R. 1977. *Rhabdocline* needle cast in the Lake States. Plant Disease Reporter. 61: 801-802.

Morton, H. L.; Zhu, Z. 1986. Variation in the incidence of Swiss needle cast among Douglas-fir provenances. Phytopathology. 76: 1114.

Rehfeldt, G. E. 1979. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. I. North Idaho and northeast Washington. Heredity. 43: 383-397.

Rehfeldt, G. E. 1982. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. II. Western Montana. Res. Pap. INT-295. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Stephan, B. R. 1973. Susceptibility and resistance of Douglas-fir provenances to *Rhabdocline pseudotsugae*. Silvae Genetica. 22: 5-6.

Stephan, B. R. 1980. Testing Douglas-fir provenances for resistance to *Rhabdocline pseudotsugae* by infection trials. European Journal of Forest Pathology. 20: 152-161.

Weir, J. R. 1917. A needle blight of Douglas-fir. Journal of Agricultural Research. 10: 99-103.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

October 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

☆ U.S. GOVERNMENT PRINTING OFFICE:1987-573-039/6

United States
Department of
Agriculture

Forest Service

**ntermountain
Research Station**

Research Note
NT-376

Forest Succession in Western Montana—a Computer Model Designed for Resource Managers

Robert E. Keane II[1]

ABSTRACT

A quantitative computer model of succession (FORSUM) has been developed for use by land managers in predicting response of forest vegetation to silvicultural treatments and wildfire. FORSUM allows evaluation of the effects of alternative treatments. The model predicts temporal changes in canopy cover for major species in four habitat types common to western Montana. Species establishment is based on regenerative strategies; then subsequent changes in cover for each species are modeled using regression equations. FORSUM also contains an easy-to-use, interactive data input routine with error checking capability and two skill levels. Output is offered in both tabular and graphic format. In a validation of FORSUM, species cover was predicted accurately 74 percent of the time. Accuracy ranged from 69 percent to 78 percent. The computer code consists of 21 subroutines and was written in FORTRAN 77. It can be modified to incorporate additional habitat types with minimal effort.

KEYWORDS: pathway model, regression, interactive program, vegetal response, succession

Predicting the composition of plant communities that arise after different silvicultural treatments or wildfire plays an important role in forest management. Because successional community composition is strongly influenced by the composition of the predisturbance vegetation and by type and intensity of disturbance, managers can manipulate successional trends to meet management objectives by selecting different silvicultural treatments (Arno and others 1985). But choosing the best treatment to meet management objectives can sometimes be difficult because there are few quantitative methods available to predict postdisturbance plant coverages. Successional classification systems such as Arno and others (1985) and Steele (1984) relate successional trends to wildfire and site treatment but yield only qualitative predictions. To overcome this problem, a study was conducted to quantify coverage response to various disturbances and then develop a computer model for predicting succession in four habitat types commonly found in west-central Montana. This model, called FORSUM (a **FOR**est **SU**ccession **M**odel), is currently available for use by land managers. The purpose of this paper is to describe the assumptions and operations of FORSUM as well as present an evaluation of the accuracy of the model.

FORSUM is based on the classification system of Arno and others (1985). In this classification system, site characteristics, predisturbance plant composition, and type and severity of treatment define major successional pathways within a habitat type phase. Plant species establishment after a disturbance is based on regenerative strategies. Subsequent growth in cover is projected using regression equations. FORSUM predicts plant coverage for 74 species of trees, shrubs, and herbs. The model is based on an analysis of 774 actual stands, including some paired treated and untreated stands. Because all data were collected within the study area defined in figure 1, it is strongly recommended that use of FORSUM not be extrapolated to areas outside these boundaries.

The model predicts succession for seven phases in the following Montana habitat types (Pfister and others 1977):

1. *Pseudotsuga menziesii/ Physocarpus malvaceus*	(PSME/PHMA)
2. *Pseudotsuga menziesii/ Vaccinium globulare*	(PSME/VAGL)
3. *Abies lasiocarpa/Xerophyllum tenax*	(ABLA/XETE)
4. *Abies lasiocarpa/Menziesia ferruginea*	(ABLA/MEFE)

These habitat types comprise more than half the forested landscape in west-central Montana. There are four treatment types represented in the model: (1) stand-replacing

---

[1] Quantitative ecologist with Systems for Environmental Management, P.O. Box 8868, Missoula, MT.

wildfire, (2) clearcut and broadcast burn, (3) clearcut and mechanical scarification, (4) clearcut with no site treatment. In addition, three severity levels are used for mechanical scarification and broadcast burn treatments and two severity levels (moderate and high) are used for wildfires. Table 1 presents the severity levels and details the criteria used to assess the severity type for a disturbed stand.

METHODS

The data base used for model construction was created by pooling data collected by Arno and others (1985) for the classification study, with data collected for a subsequent evaluation of the classification (Keane 1984). These data sets are from the Lolo and Bitterroot National Forests, the southern half of the Flathead National Forest,

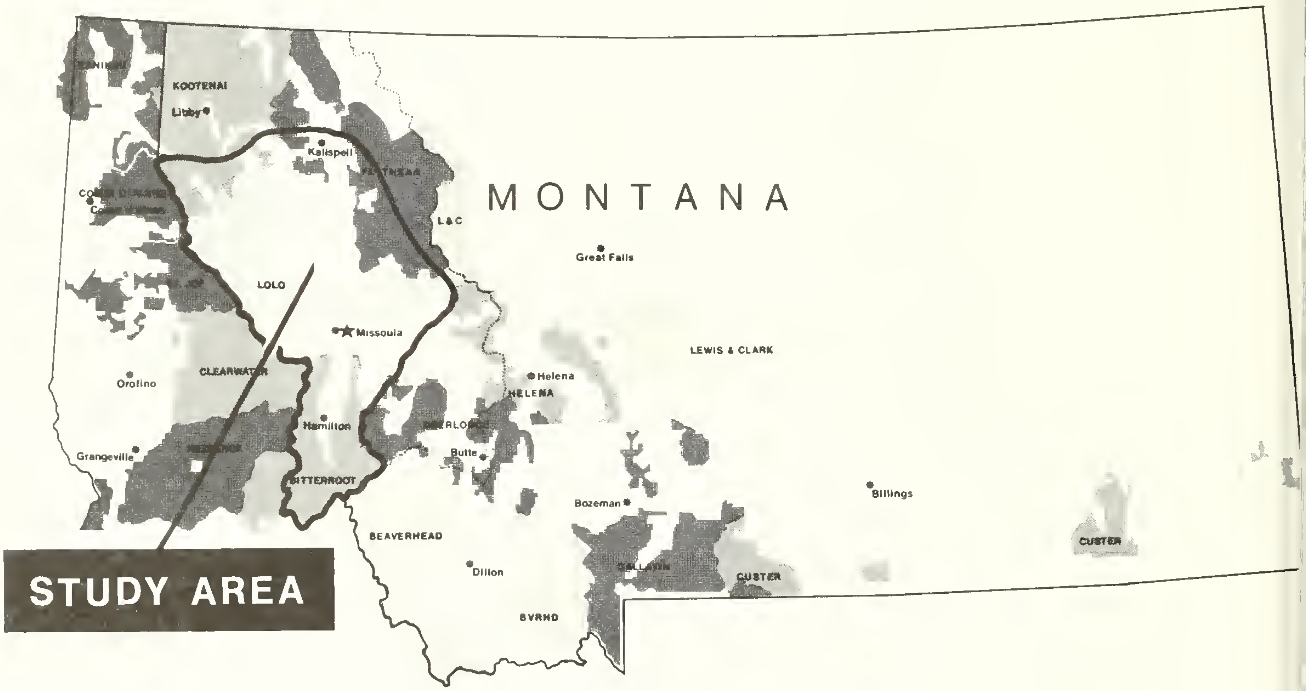


Figure 1—Area where the data were collected for model construction, and where FORSUM can be applied.

Table 1—Guidelines used in the determination of treatment severity. Wildfire or broadcast burn guidelines are partially taken from Ryan and Noste (1983)

Severity type	Treatment types	
	Wildfire or broadcast burn	**Mechanical scarification**
Low or light	Most fine fuels burned; unevenly distributed burn mosaic with some spots unburned; fresh stumps barely charred; woody plants scorched but not consumed; large woody fuels remain unburned; regeneration mostly residual.	5-25 percent of area scarified; most woody plants intact; most stumps untouched; regeneration mostly residual.
Moderate or medium	Nearly all fine fuels consumed with some of the larger woody fuel partially consumed; small areas of exposed mineral soil; some woody plants consumed; uneven or patchy distribution of fire intensity; fresh stumps charred mostly on sides.	20-40 percent of the area scarified; woody shrubs ripped up; areas of exposed mineral soil frequent but unevenly distributed.
High or heavy	Many areas of exposed mineral soil; many shrubs wholly or partially consumed; some stumps partially consumed and most are charred on top; many large woody fuels consumed; fire intensity is mostly evenly distributed.	40-100 percent of area scarified; many shrubs displaced; large areas of bare mineral soil; residual regeneration rare; many stumps and grass tussocks uprooted; evidence of some soil erosion (rill and gully).

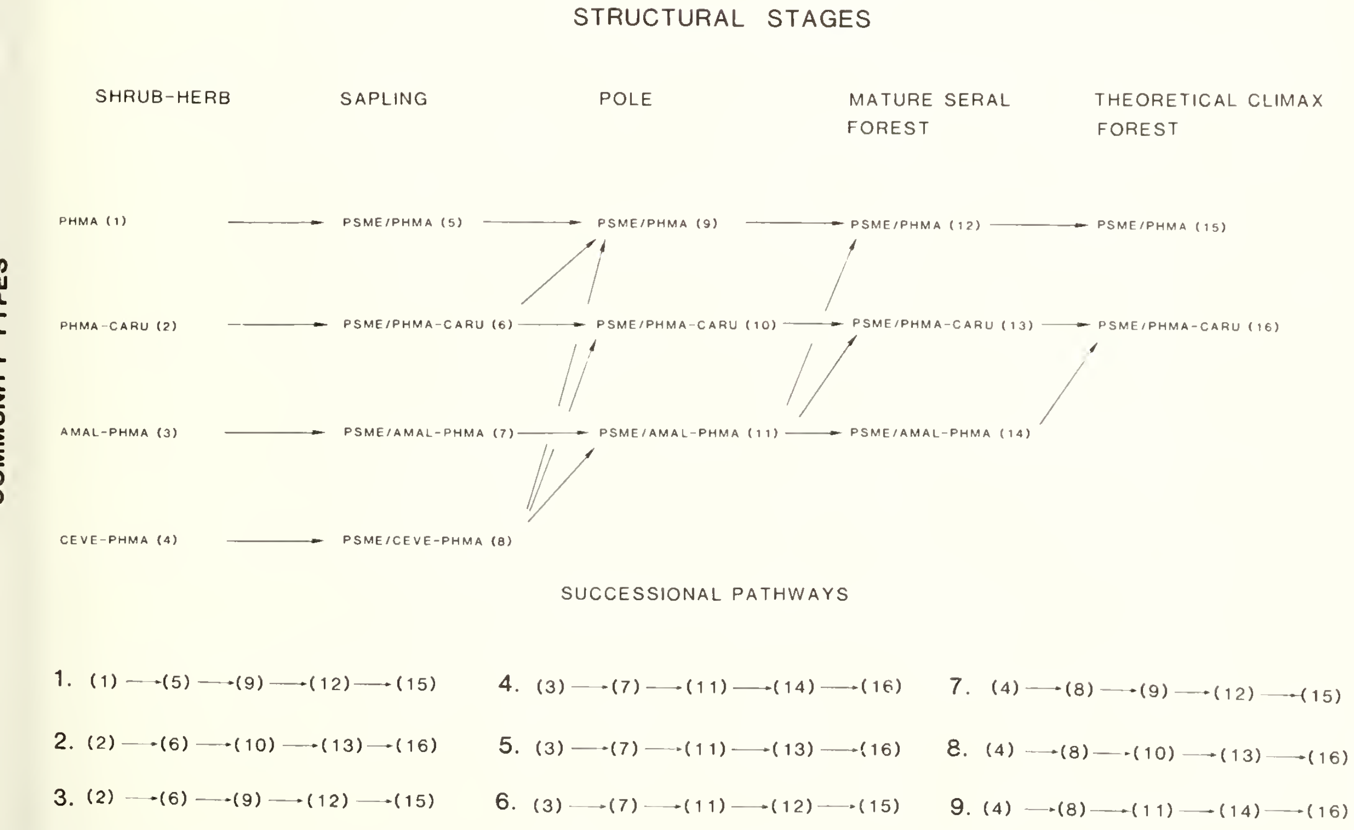
nd parts of the Flathead Indian Reservation (fig. 1). A ngle, circular, 375-m^2 macroplot was used to characterize ne vegetation in each sample stand (Arno and others 985). Canopy coverages for all woody and herbaceous becies in the macroplot were ocularly estimated using the anopy cover classes shown in table 2 (Pfister and others 977). Tree canopy coverage was estimated for each of ree structural classes: "saplings" (<4 inches d.b.h.), poles" (4 to 12 inches d.b.h.), and "mature trees" (>12 nches d.b.h.). Other important site and stand variables ecorded include elevation, aspect, slope, stand age, type, nd general severity of treatment, average d.b.h. of dominant trees in the stand, and stand basal area. Data from many adjacent treated and untreated stands on the same sites were taken to allow interpretations of treatment response, with minimal site-related differences.

Table 2—Cover classes and cover percentages as used in the FORSUM model

Cover class code	Percent canopy cover
0	no canopy cover
T	0.1 to 0.5
1	0.5 to 5.0
2	5.0 to 25.0
3	25.0 to 50.0
4	50.0 to 75.0
5	75.0 to 95.0
6	95.0 to 100.0

The first step in constructing FORSUM was inspecting the sampled data to select the most frequently occurring plant species in each habitat type for modeling. Then the selected species were subjectively categorized into ecological groups based on their method of establishment, relative shade tolerance, and life form (Keane 1985a). These ecological groups were used as guidelines for the establishment of a species after various simulated perturbations. For example, since *Ceanothus velutinus* produces seeds that can remain viable in the soil for many decades, it was placed in the ecological group Soil Seed Bank Plants. The guidelines for establishment of plants in this group are (1) seeds can only germinate after a moderate-to high-severity fire; (2) the plant need not be visible on the predisturbance site, but it must be present in nearby stands of similar environmental characteristics; and (3) the perturbation must remove the forest overstory. These guidelines were programmed into a subroutine for inclusion in the final FORSUM program.

Next, the data were stratified by successional pathway (example shown in fig. 2). Each pathway is a consequence of type and severity of disturbance and predisturbance composition. A multiple regression analysis was then performed on the data in each pathway. Variables were



igure 2—Successional pathways recognized in the PSME/PHMA,DRY habitat type phase. hese pathways were the most common and contained adequate data for regression nalysis. Numbers next to community name denote community number. Successional athways (below) are designated by sequences of community type numbers.

chosen for inclusion in regression analysis based on interpretations of many graphs and scattergrams. The Stepwise Regression method (SPSS 1983) was then used to produce final regression equations for each pathway from each set of selected variables. These equations predict species canopy coverage from site, type and severity of treatment, vegetational variables, and various transformations of all these variables. Each species has a unique regression equation for each successional pathway. All regression coefficients and equation forms were stored in computer data files for access by the main computer program.

Once regression analysis was completed, the model was then programmed in FORTRAN 77 computer language, using regression equations as the foundation of the program. To compensate for programming and data limitations, certain assumptions had to be made:

1. The successional pathways defined by Arno and others (1985) accurately represent forest succession for these habitat type phases.
2. In any individual pathway or treatment, each plant species has only one main method of establishment or expansion; all other methods are assumed to be insignificant. But a species might have more than one method of expansion across treatments, pathways, and habitat type phases.
3. Vegetatively reproducing plants are only present in the postdisturbance community if they were present in the predisturbance community. Thus reproduction from seed for these types of plants is considered minimal.
4. There is always a seed source for all modeled trees in a habitat type phase.

After FORSUM was programmed, an additional 29 paired (treated and untreated) sites were sampled throughout the study area for a test of the model. More than one treated stand was sometimes sampled on a site. Although not every pathway could be tested with only 29 sample sites, this "validation" does provide a measure of model accuracy. In this "validation" procedure, data from the untreated (mature) stands were used as inputs to FORSUM. The type and intensity of treatment were then specified, generating predictions of posttreatment plant coverages. These predictions were compared to the actual cover data collected for treated (disturbance) stands. Percent accuracy was determined by dividing number of correct cover predictions by the total number of predictions.

RESULTS AND DISCUSSION

Results of the multiple regression analysis yielded approximately 2,000 equations, with coefficients of determination (R^2) ranging from 0.29 to 0.99, and standard errors about the regression line ($S_{y \cdot x}$) ranging from 0.001 to 23.905 expressed as a percent (table 3). Number of observations (n) used to construct equations ranged from 3 to 89, with an average of approximately 55 observations. There is a regression equation for each species in each pathway for a habitat type phase. Table 4 shows some examples of regression equations. An interesting result of

Table 3—Summary statistics for FORSUM regression analysis. Statistics are stratified by habitat type phase (Arno and others 1985)

	Habitat type phase[1]						
Summary statistic[2]	**PSME/ PHMA, DRY**	**PSME/ PHMA, MOIST**	**PSME/ VAGL, XETE**	**ABLA/ XETE, VAGL**	**ABLA/ XETE, VASC**	**ABLA/ MEFE, WARM**	**ABLA/ MEFE, COLD**
Number of pathways	9	6	8	8	9	6	8
Number of species	38	40	36	34	30	43	37
Number of equations	342	240	288	272	270	258	296
Average number observations (n)	23	16	36	33	22	22	18
Range of observations (n)							
Low	4	4	5	4	3	6	5
High	83	44	88	89	55	57	54
Average R^2	0.74	0.71	0.76	0.72	0.70	0.75	0.76
Range of R^2							
Low	0.42	0.31	0.36	0.35	0.32	0.34	0.29
High	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Average $S_{y\,x}$	4.667	4.628	3.747	4.463	3.851	3.828	3.737
Range of $S_{y\,x}$							
Low	0.010	0.001	0.001	0.011	0.223	0.003	0.001
High	23.095	20.041	17.773	20.098	21.077	19.880	20.110
Total number of regression equations: 1,966							

[1]PSME = *Pseudotsuga menziesii* (Douglas-fir)
ABLA = *Abies lasiocarpa* (subalpine fir)
VAGL = *Vaccinium globulare* (blue huckleberry)
VASC = *Vaccinium scoparium* (grouse whortleberry)
MEFE = *Menziesia ferruginea*
XETE = *Xerophyllum tenax* (beargrass).
[2]R^2 = coefficient of determination; $S_{y\,x}$ = standard error about the regression line. Note: units are in percent.

Table 4—Examples of regression equations used to predict successional plant cover in the model FORSUM

Habitat type phase	Pathway	Dependent or *Y* variable	Remainder of regression equation with the independent variables
PSME/PHMA,DRY	4	SYAL[1]	= 1.910 + 0.658(PRED) + 22.745(1/CC)
PSME/PHMA,MOIST	3	PHMA	= 2.002 + 0.970(PRED) + 0.023(AGE)
ABLA/MEFE,WARM	1	VAGL	= 3.256 – 0.031(SLP) + 0.023(AGE)

[1] Variable definitions:

SYAL - Percent canopy cover of *Symphoricarpos albus* or snowberry.
PHMA - Percent canopy cover of *Physocarpus malvaceus* or ninebark.
VAGL - Percent canopy cover of *Vaccinium globulare* or huckleberry.
PRED - Predisturbance cover (in percent) of the dependent or *Y* variable.
CC - Percent canopy cover of all overstory tree species.
AGE - Successional age of stand in years.
SLP - Slope of stand in percent.

e regression analysis was the importance of predistur- ance species cover for predicting postdisturbance cover. nis is consistent with the theory of Egler (1954) and the ndings of Lyon and Stickney (1976).

The FORSUM program is composed of 21 subroutines nd a main driver. It has an interactive routine with error necking capability that makes it easy to enter data and se the model for predicting vegetation cover resulting om different treatments. The interactive routine was esigned to accommodate two levels of expertise, one uiding inexperienced users through every step, and a se- ond, streamlined version for quick data entry. A general- ed flow chart showing the use of FORSUM is presented figure 3. Once input values are entered, FORSUM keys ne appropriate successional pathway from habitat type nase, treatment type, severity type, and vegetation overage for the pretreatment community. The program nen accesses the pertinent regression equations from ex- ernal computer files and uses them to calculate posttreat- ent coverage predictions for each species. The user can noose to display (on the computer terminal) or print (to a ne printer) graphs and tables of cover predictions (ex- mples are shown in figs. 4 and 5). Also, the user may ew three important statistics for the regression equation sed to predict successional cover: coefficient of deter- nination (R^2), number of observations (n), and standard eviation about regression ($S_{y \cdot x}$).

Testing or "validation" results (table 5) showed that the nodel averaged 74 percent accuracy in predicting the cor- ect cover class for all species. More importantly, the suc- essional pathway was never misidentified. Tree species roved to be more difficult to model (65 percent accurate) nan undergrowth species (82 percent accurate). This was robably due to the inherent variability involved when ees became established from seed rather than from egetative sprouts. Predictions for clearcutting followed y broadcast burning or mechanical scarification were nore accurate (79 percent) than predictions for wildfire or earcutting with no site preparation (71 percent). Perhaps nis is because broadcast burns and mechanical scarifica- ons create more uniform conditions in the stand than ildfire or no site preparation. The model averaged 87 ercent accuracy within (plus or minus) one cover class. his gain in accuracy was mostly in the smaller cover asses (cover class T and cover class 1), which could be ombined for use in management planning.

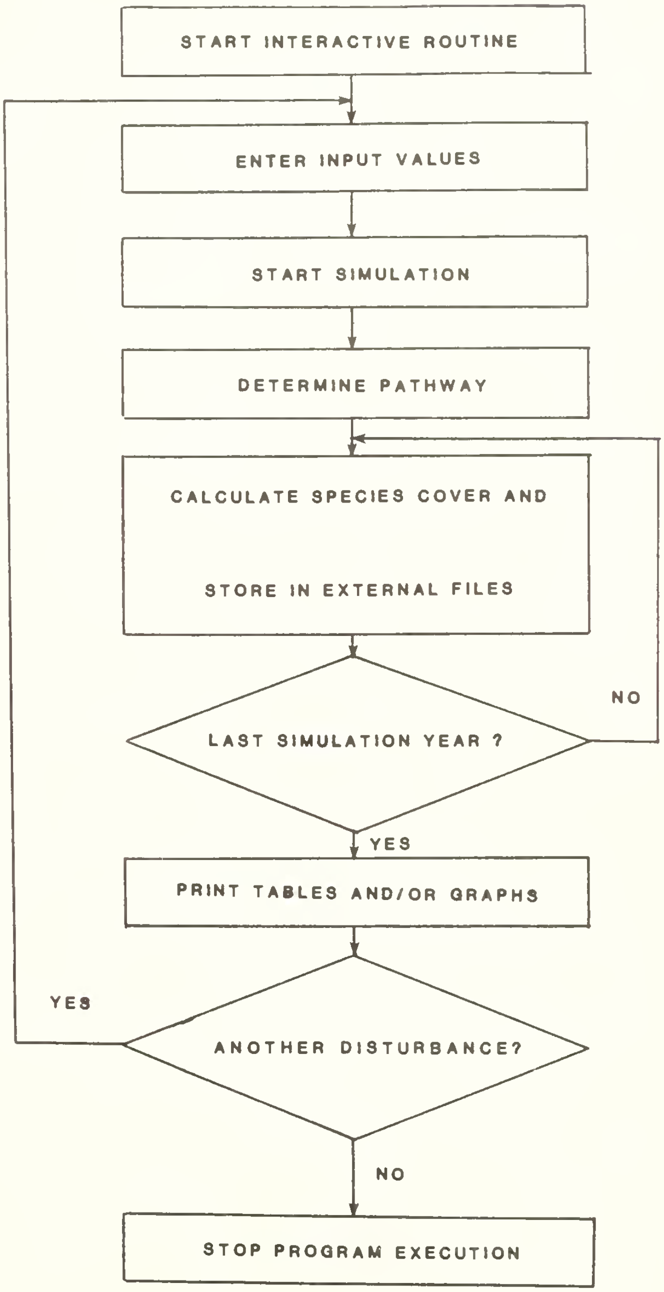
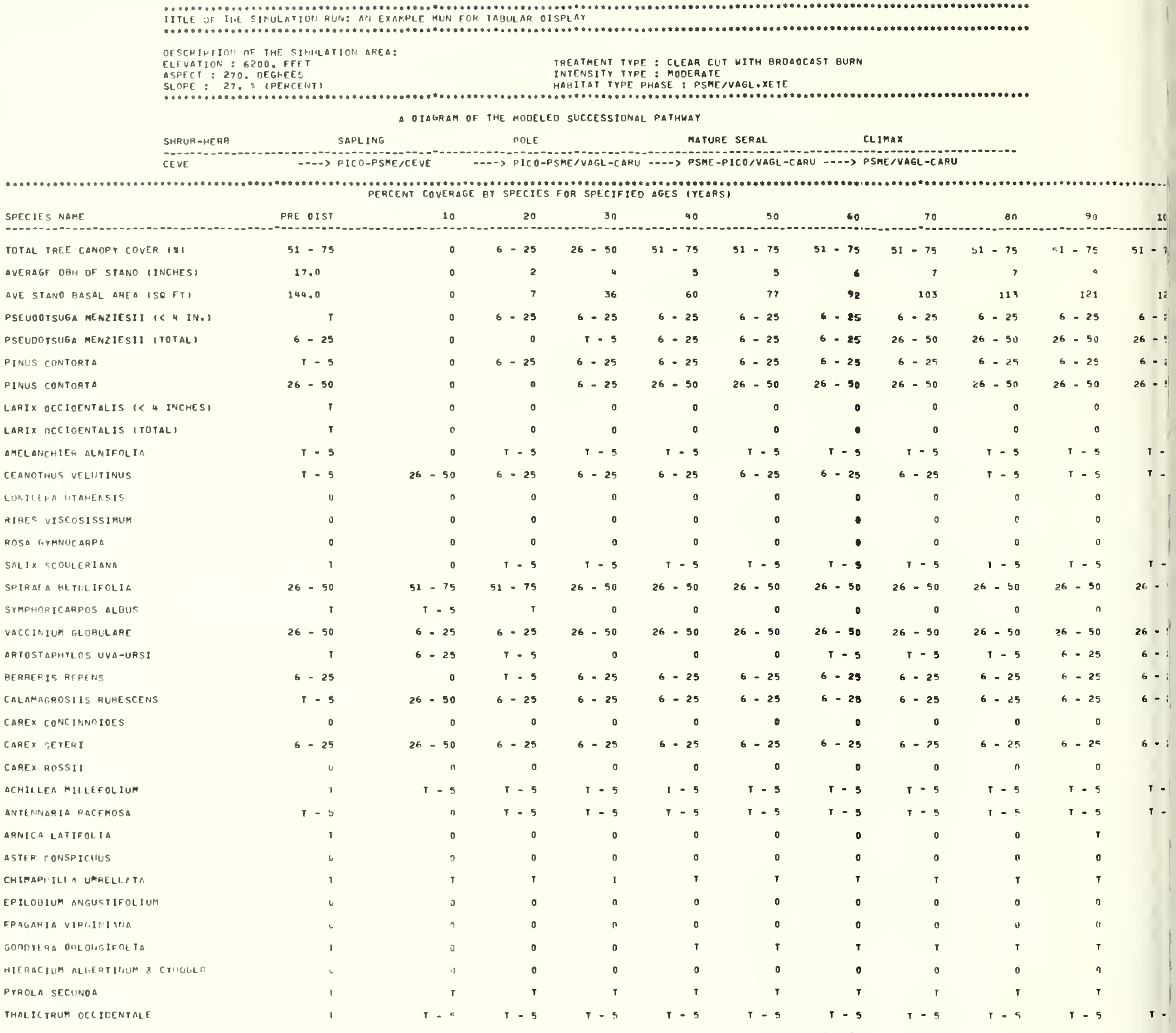
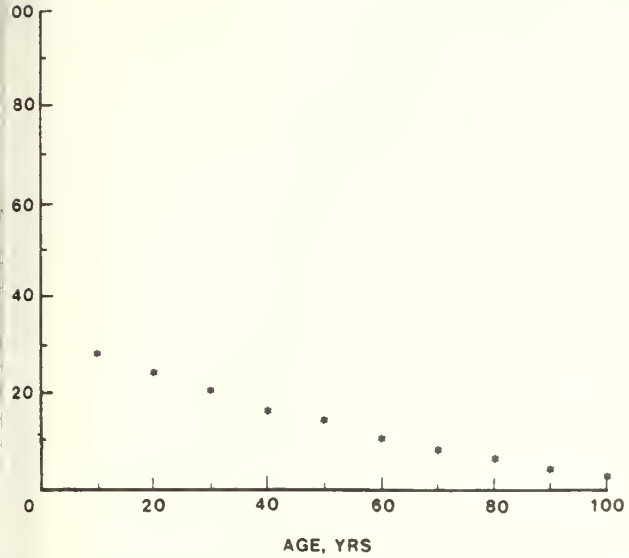


Figure 3—Flow chart of FORSUM succession model.



```
                              ****************************************************************************************************
                              TITLE OF THE SIMULATION RUN: AN EXAMPLE RUN FOR TABULAR DISPLAY
                              ****************************************************************************************************

                              DESCRIPTION OF THE SIMULATION AREA:
                              ELEVATION : 6200. FEET                          TREATMENT TYPE : CLEAR CUT WITH BROADCAST BURN
                              ASPECT : 270. DEGREES                           INTENSITY TYPE : MODERATE
                              SLOPE :  27. % (PERCENT)                        HABITAT TYPE PHASE : PSME/VAGL.XETE
                              ****************************************************************************************************

                                                     A DIAGRAM OF THE MODELED SUCCESSIONAL PATHWAY

                              SHRUB-HERB              SAPLING                POLE                   MATURE SERAL           CLIMAX
                              --------------------------------------------------------------------------------------------------
                              CEVE              ----> PICO-PSME/CEVE    ----> PICO-PSME/VAGL-CARU ----> PSME-PICO/VAGL-CARU ----> PSME/VAGL-CARU

*************************************************************************************************************************************************
                                                   PERCENT COVERAGE BY SPECIES FOR SPECIFIED AGES (YEARS)

SPECIES NAME                            PRE DIST          10        20        30        40        50        60        70        80        90        10
-------------------------------------------------------------------------------------------------------------------------------------------------

TOTAL TREE CANOPY COVER (%)              51 - 75           0    6 - 25   26 - 50   51 - 75   51 - 75   51 - 75   51 - 75   51 - 75   51 - 75    51 - 7

AVERAGE DBH OF STAND (INCHES)            17.0              0         2         4         5         5         6         7         7         9

AVE STAND BASAL AREA (SQ FT)             144.0             0         7        36        60        77        92       103       113       121        1

PSEUDOTSUGA MENZIESII (< 4 IN.)                T           0    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     6 -

PSEUDOTSUGA MENZIESII (TOTAL)             6 - 25           0         0     T - 5    6 - 25    6 - 25    6 - 25   26 - 50   26 - 50   26 - 50    26 -

PINUS CONTORTA                             T - 5           0    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     6 -

PINUS CONTORTA                           26 - 50           0         0    6 - 25   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50    26 -

LARIX OCCIDENTALIS (< 4 INCHES)                T           0         0         0         0         0         0         0         0         0

LARIX OCCIDENTALIS (TOTAL)                     T           0         0         0         0         0         0         0         0         0

AMELANCHIER ALNIFOLIA                      T - 5           0     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T -

CEANOTHUS VELUTINUS                        T - 5     26 - 50    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     T - 5     T - 5     T -

LONICERA UTAHENSIS                             0           0         0         0         0         0         0         0         0         0

RIBES VISCOSISSIMUM                            0           0         0         0         0         0         0         0         0         0

ROSA GYMNOCARPA                                0           0         0         0         0         0         0         0         0         0

SALIX SCOULERIANA                              1           0     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     1 - 5     T - 5     T -

SPIRAEA BETULIFOLIA                      26 - 50     51 - 75   51 - 75   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50    26 -

SYMPHORICARPOS ALBUS                           T       T - 5         T         0         0         0         0         0         0         0

VACCINIUM GLOBULARE                      26 - 50      6 - 25    6 - 25   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50   26 - 50    26 -

ARTOSTAPHYLOS UVA-URSI                         T      6 - 25     T - 5         0         0         0     T - 5     T - 5     T - 5    6 - 25     6 -

BERBERIS REPENS                           6 - 25           0     T - 5    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     6 -

CALAMAGROSTIS RUBESCENS                    T - 5     26 - 50    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     6 -

CAREX CONCINNOIDES                             0           0         0         0         0         0         0         0         0         0

CAREX GEYERI                              6 - 25     26 - 50    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25    6 - 25     6 -

CAREX ROSSII                                   0           0         0         0         0         0         0         0         0         0

ACHILLEA MILLEFOLIUM                           1       T - 5     T - 5     T - 5     I - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T -

ANTENNARIA RACEMOSA                        T - 5           0     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T -

ARNICA LATIFOLIA                               1           0         0         0         0         0         0         0         0         T

ASTER CONSPICUUS                               0           0         0         0         0         0         0         0         0         0

CHIMAPHILA UMBELLATA                           1           T         T         I         T         T         T         T         T         T

EPILOBIUM ANGUSTIFOLIUM                        0           0         0         0         0         0         0         0         0         0

FRAGARIA VIRGINIANA                            0           0         0         0         0         0         0         0         0         0

GOODYERA OBLONGIFOLIA                          1           0         0         0         T         T         T         T         T         T

HIERACIUM ALBERTINUM & CYNOGLO                 0           0         0         0         0         0         0         0         0         0

PYROLA SECUNDA                                 1           T         T         T         T         T         T         T         T         T

THALICTRUM OCCIDENTALE                         1       T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T - 5     T -

XEROPHYLLUM TENAX                        26 - 50      6 - 25     T - 5    6 - 25    6 - 25    6 - 25   26 - 50   26 - 50   26 - 50   26 - 50    51 -
```

Figure 4—Sample of a tabular output from FORSUM for a sample stand.



gure 5—Sample of graphic output
om FORSUM for shinyleaf ceanothus
eanothus velutinus = CEVE).

able 5—The model validation summary. Accuracy of predictions is presented by habitat type phase. The first category of accuracy is computed by dividing the number of correct predictions by the total number of predictions. The second type of accuracy is computed by dividing the total number of predictions within a cover class of the observed value by the total number of predictions. The number in parentheses indicates number of stands sampled for the phase

Habitat type phase[1]	Overall accuracy of predictions	Accuracy within ± one cover class
	Percent	
SME/PHMA,DRY	78 (13)	85 (13)
SME/PHMA,MOIST	73 (7)	84 (7)
BLA/XETE,VAGL	71 (14)	86 (14)
BLA/XETE,VASC	77 (10)	89 (10)
BLA/MEFE,WARM	69 (12)	86 (12)
BLA/MEFE,COLD	73 (8)	90 (8)
All Phases	74 (64)	87 (64)

[1]The PSME/VAGL,XETE habitat type phase was not sampled.

ONCLUSIONS AND MANAGEMENT MPLICATIONS

FORSUM seems to overpredict cover in younger age
asses and underpredict in older age classes. This is prob-
bly a result of inadequate data representation for all age
asses. Successional pathways with minimal plant divers-
y are more accurately modeled, suggesting that site fac-
rs play a more important role than competition in the
ss diverse habitat types. Regression equations are prob-
bly the weakest part of FORSUM. Results of validation
dicate that data sets upon which the model was built do
ot fully represent the variation found in natural stands. To mitigate this weakness, it is important that model results be used only in the study area (fig. 1). Lastly, the most sensitive routine in FORSUM is the keying of successional pathway. If the pathway is miskeyed, the wrong set of regression equations is chosen. Fortunately, validation has shown this to be a strong predictive part of the model.

FORSUM is currently available for use on Perkin-Elmer and Data General minicomputer systems and UNIVAC mainframe computers.[2] It was designed so additional habitat types can be added to the model with minimal modification. The user's manual (Keane 1985b) presents important information concerning programming considerations and execution procedures.

The main use of FORSUM is the prediction of the coverage of undergrowth and tree species as a result of different treatments. For instance, a forester might use the model to see if shrub and grass cover will be great enough to inhibit either natural or planted tree regeneration. A wildlife or range specialist might use it to assess alternative treatments for increasing certain forage species on a site. Vegetation response predictions could be compared to assess impacts of various treatments on watershed values or on visual quality. Nevertheless, it is important that the user understand that model predictions are only general trends in cover changes during succession.

ACKNOWLEDGMENTS

This paper is a result of cooperation between the University of Montana and the USDA Forest Service, Intermountain Research Station. Acknowledgment is due to Wendel Hann of the Northern Region Ecosystem Management Program and Hans Zuuring of the University of Montana Forestry School for creative and technical advice and consultation. The following people also contributed to the technical aspects of the paper: Dr. Steven Running and Dr. James Habeck of the University of Montana; Dennis Simmerman, Dennis Ferguson, Robert Steele, and Gordon Booth of the Intermountain Research Station; and Jack Losensky of the Lolo National Forest.

REFERENCES

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 74 p.

Egler, F. E. 1954. Vegetation science concepts: 1. Initial floristic composition - a factor in old field vegetation development. Vegetatio. 4: 412-417.

Keane, R. E. 1984. An evaluation of a successional classification system. Final report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT. 44 p.

---

[2]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Keane, R. E. 1985a. Predicting successional plant composition on a *Pseudotsuga menziesii/Physocarpus malvaceus* habitat type in west-central Montana. Missoula, MT: University of Montana. 95 p. Thesis.

Keane, R. E. 1985b. User's guide to FORSUM: a FORest SUccession Model. Final report on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT. 66 p.

Lyon, L. J.; Stickney, P. F. 1974. Early vegetal succession following large northern Rocky Mountain wildfires. Proceedings of the 14th Annual Tall Timbers Fire Ecology Conference; 1974 October 8-10; Missoula, MT. Tallahassee, FL: Tall Timbers Research Station: 355-375.

Pfister, R. E.; Kovalchik, B.; Arno, S.; Presby, R. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 80 p.

Ryan, K. C.; Noste, N. V. 1983. Evaluating prescribed fires. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W., tech. coords. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 230-238.

SPSS, Inc. 1983. SPSSX user's guide. Chicago: McGraw-Hill. 802 p.

Steele, R. 1984. An approach to classifying seral vegetation within habitat types. Northwest Science. 58: 29-39.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

October 1987

Intermountain Research Station
324 25th Street
Ogden, UT 84401

ed States
artment of
culture

est Service

rmountain
earch Station

earch Note
-377

Improved Streamflow and Water Quality Monitoring Using a Microprocessor-Based System

Ronald E. Babbitt[1]

3STRACT

)escribes microprocessor-based data acquisition system for nitoring streamflow and collecting water samples at ıote sites. This system was more efficient and provided rp precise data during high-intensity, short-duration nstorms than the system used previously.

YWORDS: watershed management, hydrological monitoring, data acquisition, stream sedimentation, erosion, environmental monitoring, electronic monitors

TRODUCTION

Accurate data quantifying effects of road construction, ıber harvesting, and other forest management activities water quality are often essential for evaluation of land nagement activities. Collecting such information has en difficult and costly for the Forest Service due to the noteness of many sites and limitations of available mpling equipment. Advances in electronic technology now ıke possible microprocessor-based systems that reduce ts and enhance the information collected. The purpose of s report is to inform hydrologists and others about the oabilities of modern electronic monitoring devices.

ARLY METHODS AND EQUIPMENT

Personnel with the Nez Perce National Forest and the ermountain Research Station have been studying effects road construction and timber harvesting on soil and water sources in the Horse Creek drainage, which is a part of the eadow Creek barometer watershed, located near Elk City, . Project objectives call for measuring sediment producn resulting from road construction.

As one approach, gaging stations with 1-ft H-flumes and tomatic water sampling equipment were located on streams immediately above (station A) and below (station B) road crossings. The streamflow at station A was essentially free from effects of road construction and thus provided the control. Streamflow at station B was influenced by the road construction primarily through the additional flow coming in from the ditch on the cut-bank side of the road during rainstorms and snowmelt. A primary goal was the collection of high-resolution streamflow data and water samples during high-intensity, short-duration storms. Although the equipment is reliable, collecting such data during high-intensity, short-duration storms has proven difficult due to the limited bottle capacity and the types of triggering modes afforded by the automatic samplers. Moreover, precise synchronization of station A and station B flow records and water samples using standard equipment was not possible without equipment modifications.

Figure 1 is the stage record of a lower road crossing station (station B) for May 23, 1981. The spike near the center of the graph resulted from a thunderstorm that started just before 3 p.m. and dropped about 0.5 inch of

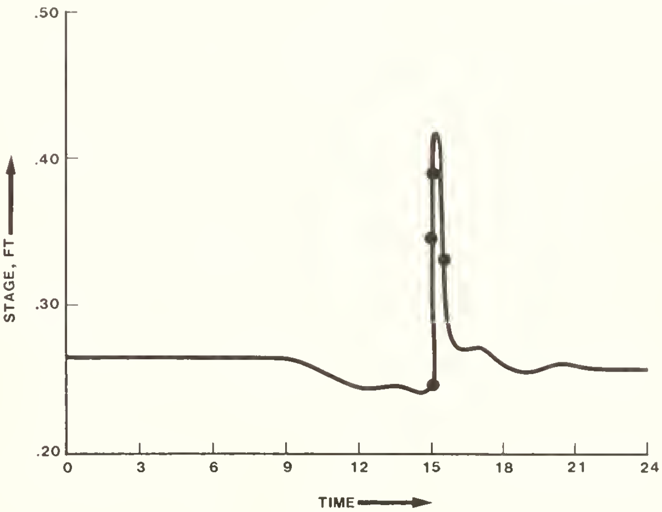


Figure 1—Stage record, May 23, 1981, road crossing #16, station B. (Dots indicate water sample collection points.)

---

[1]Electronics technician located at Intermountain Station's Forestry iences Laboratory, Missoula, MT.

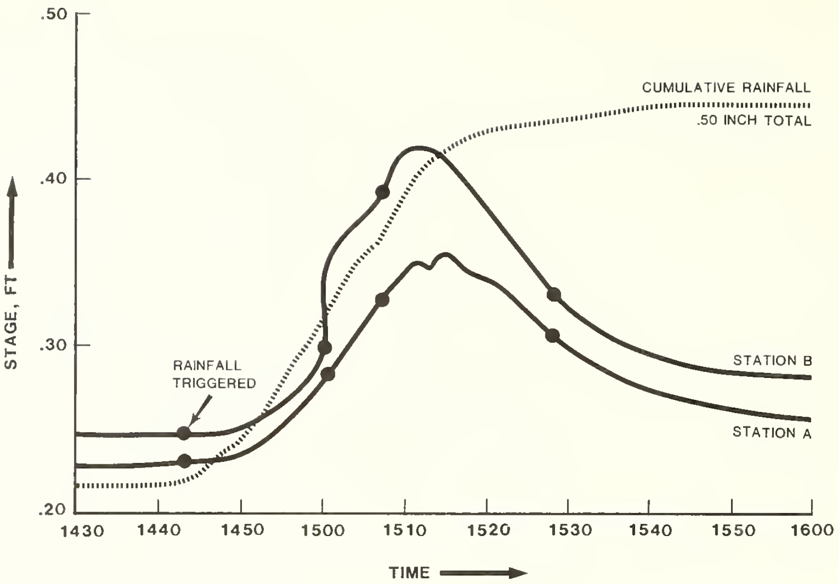


Figure 2—Cumulative rainfall and stage records, May 23, 1981, 4:30 to 6 p.m., road crossing #16, stations A and B. (Dots indicate water sample collection points.)

rainfall over 40 minutes. Providing much higher resolution of the same storm, figure 2 is a "window" from 2:30 p.m. to 6 p.m. and contains stage records from station A and station B, as well as cumulative rainfall.

Consider now the battery-powered sampler's capabilities—28 bottles and either fixed-time interval or flow-proportional sampling. If the service interval is once per week and operation is in time mode, four samples per day are required to maximize sampler efficiency. Thus, the probability of taking a sample during a 1/2-hour thunderstorm is only 0.08. Referring again to figure 1, and assuming samples were taken every 6 hours, starting at midnight, then indeed, no meaningful samples would have been collected. Moreover, service intervals of once per week to remote sites are costly and time consuming, and intervals of once per month more reasonable and typical.

Flow-proportional sampling, in which a sample is collected after a specified quantity of water has passed, is not much better, as most of the data again will be of base flow conditions. Only by chance would a sample be taken during an event such as that shown in figure 1; and even then its timing would depend on when the last sample was taken, not on the characteristics of the event itself. Clearly, techniques synchronizing storm events to the collection of samples are desirable in these situations.

Initially, a multipoint probe system was designed to trigger the sampler as the water level rose or fell between the points. Although sampler efficiency increased, this system was impractical as it was necessary to completely rewire the probe if altered sample points were required. Additionally, the streamflow strip chart recorder required modification to include an extra pen to mark the sample event.

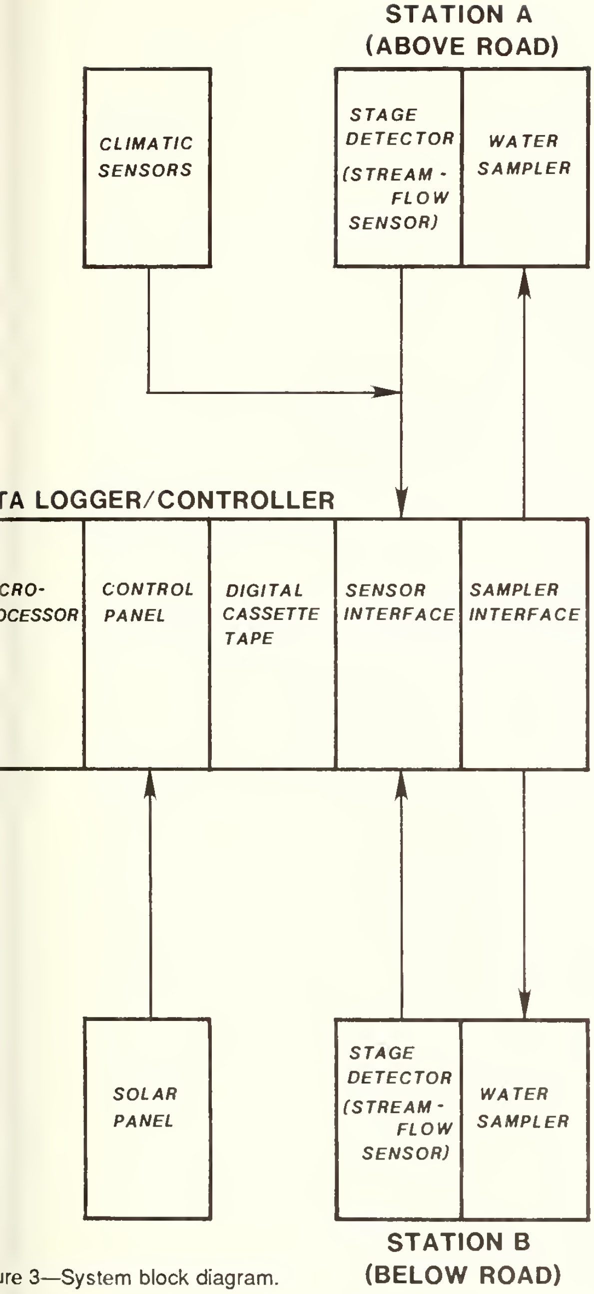
MICROPROCESSOR SYSTEM

Microprocessor system components operating over wide temperature ranges and requiring minuscule amounts of power became available in the late 1970's. Because micr
processor systems would substantially enhance the water sample collection process, a design effort was undertaken
meet the following objectives:

1. Sample collection activated by:
    a. Rising or falling stage
    b. Time interval (baseline information, typically onc
    per week)
    c. Rainfall intensity.
2. Measure climatic parameters, as well as streamflow data.
3. Store pertinent data on cassette tape (6 month minimum capacity).
4. Trigger samplers above and below road simultaneously, based on data from lower station.
5. Operate for extended periods on battery-supplied power.
6. Operate under extreme environmental conditions.

Because of the lack of availability of system and circuit board level components suitable for field use, a completely new design was required. Design and fabrication of a prototype system was completed in February 1981. After weeks of testing and calibration, the unit was installed at
road crossing gauging station in the Horse Creek drainage
A second system was installed in June of 1982, and both remained in operation until October 1983. The system (se
block diagram, fig. 3) consists of a microprocessor, sensor and sampler interfaces, climatic and streamflow sensors, digital cassette tape, and control panel. In addition, a sola
charging circuit was added to increase system reliability a
to eliminate the need to change batteries.

An algorithm of the four methods leading to the triggeri
of the automatic samplers is given in figure 4. Samples ar
taken every 7 days at 12 p.m., providing baseline data. As with other key variables in the microprocessor system, this interval can be altered to suit the user's needs. The majori
of samples collected are initiated by changes in stage as



ıre 3—System block diagram.

asured by a pressure sensor. Water level fluctuations nificant enough to cross threshold levels trigger the omatic sampler, at which time new threshold levels are culated and set. The magnitude of the increment setting new threshold level can be altered via the front panel board. Falling stage increment is calculated to be twice keyboard entered value; that is, the stage must fall two rements before the triggering threshold is crossed. This hnique further extends service intervals without sacrific- the more important rising stage information.

different triggering method, based on rainfall rate, was plemented to take a sample at the onset of a thunder- rm. If the rainfall, as measured by a tipping bucket rain ıge, exceeds a preset value over a 4-minute interval, then ample is taken. Because a sample collected by this tech- ue is desired only at the start of a storm, subsequent nfall triggers are inhibited for 24 hours. Lastly, sample initiation can be accomplished through keyboard controls, providing servicing personnel a means to check system performance. Referring to figures 1 and 2, the dots mark the stage levels where samples were taken. The first sample was rain-induced, the next two were taken on the rising stage, and the final one was collected on the falling stage.

Sampling based on the algorithm described above has worked well for the Horse Creek study, but is only one of many schemes possible. Other techniques could include rate of change of streamflow, or triggering based on other parameters, such as cumulative solar radiation for sampling during snowmelt periods. Indeed, microprocessor systems are extremely versatile because their function can be altered significantly without extensive hardware modification. It should be noted that this added flexibility in itself will not optimize the collection of water samples; the hydrologist must select suitable sample initiation levels.

All information collected is stored digitally, which offers a much higher degree of resolution than available with analog methods. Using conventional strip charts for long-term recording instruments mandates slow chart speeds and a subsequent loss of resolution. Electronic memories or digital cassette tapes are far superior to strip charts for storage of data. It would be very difficult to obtain resolution of a strip chart to the degree shown in figure 2.

Another important consequence of electronic data recording is ease of transferring field information to a larger computer for long-term storage and analysis. Large backlogs of strip charts to be read often occur because the transcribing process is both tedious and time consuming. Several months of streamflow, rainfall, air temperature, and other data can typically be transferred from digital cassette tape in a matter of minutes. Errors in transcribing the data are virtually eliminated using digital methods, as the error rate is less than one in a million. Hydrographs can be constructed via a computer and plotter from the digital data, if desired.

But the system was not without problems. Foremost was accuracy and reliability of the pressure sensors used to measure water stage. Original sensors exhibited a high degree of hysteresis, resulting in jumps in the data instead of a smooth progression. Further, freezing water would burst the sensing diaphragm, destroying the sensor. New, more expensive pressure sensors eliminated the "jumpy" data, but no reasonable solution to the freezing problem has been found.

Another difficulty was the "unfriendliness" of the system. For maximum utility personnel must be comfortable with the operation of any piece of equipment. This system posed problems because some of the key variables are listed in octal (instead of decimal), and values are entered via a hexadecimal keyboard.

COST

Cost estimates for automatic sampling equipment required to measure sediment production at a road crossing site are given in table 1. Cost of the microprocessor controller varies with the wages for approximately 60 hours of labor needed to assemble a single unit (wages of $20.00 to $80.00 per hour were used). Instruments measuring climatic parameters, such as rainfall, are more expensive

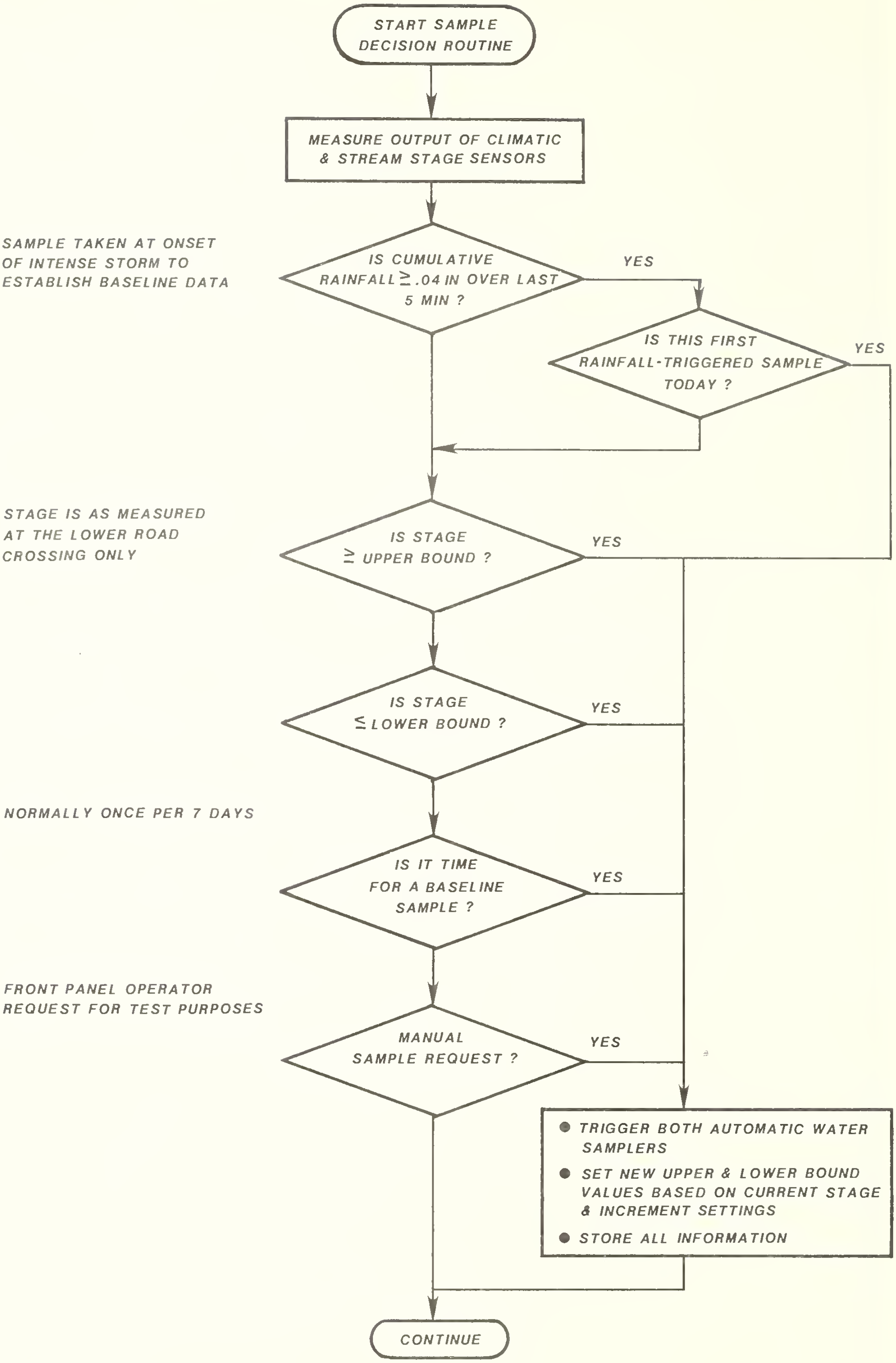


Figure 4—Water sample initiation algorithm.

Table 1—Purchase price comparison of hardwire and microprocessor systems

Equipment descriptions	Hardwire systems	Microprocessor system
	Dollars	*Dollars*
Sampler (2)	3,900	3,900
Flowmeter (2)	3,500	3,500
Flow recorder (2)	2,400	
Fiberglass 1-ft H-flume with approach (2)	800	800
Microprocessor controller		[1]4,200-7,800
Climatic instrumentation	1,700	500
Total	12,300	12,900-16,500

[1]Range variance due to assembly costs, see text.

when used in conjunction with the hardwired logic system, because each requires a self-contained data-logging device. Shelter costs, which can add substantially to the total, are not included in the table as they will vary considerably, depending on such factors as length of measuring period, vandalism protection, snow accumulations, and other factors.

Due to the dissimilarity of operation and output between the systems it is difficult to compare operating costs. Direct savings will be realized through extended service intervals and reduced data transfer costs associated with the microprocessor system. The real value of the microprocessor system lies in those applications requiring improved sample distributions, reduced error rates, and integrated data sets.

In the period since this system was designed, low-power, single-board microprocessor systems suitable for field use have become available. A streamlined version of the system described here could be assembled from commercially available circuit boards, substantially reducing the fabrication effort as well as the cost.

For further information regarding this system or suggestions on assembling an updated version, please contact:

Ronald Babbitt
Forestry Sciences Laboratory
P. O. Box 8089
Missoula, MT 59807

November 1987
Intermountain Research Station
324 25th Street
Ogden, UT 84401

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-378

April 1988

Soil Temperatures and Suckering in Burned and Unburned Aspen Stands in Idaho

Roger D. Hungerford[1]

ABSTRACT

Monthly average soil temperatures in a burned aspen stand ranged from 0 to 8 °F higher than in the unburned stand at depths to 12 inches for a site in southeastern Idaho. From June through August the first year after burning, soil temperatures were significantly different at all depths in burned and unburned stands. By the second and third years after burning, temperatures were not significantly different for most months. Temperatures were favorable for sucker initiation on burned plots. A hypothesis for a temperature threshold of 60 °F for sucker initiation is discussed.

KEYWORDS: *Populus tremuloides*, quaking aspen, root suckers, temperature, fire

SOIL TEMPERATURE AND SUCKERING

Many quaking aspen (*Populus tremuloides* Michx.) stands in the West are overmature and decadent, with conifer, shrub, and grass successional stages replacing aspen (Mueggler 1985). Historically, most even-aged aspen stands appear to be the result of fire (Jones and DeByle 1985) and thus seem to require a disturbance such as fire or cutting for rejuvenation. Aspen trees are extremely sensitive to fire because of their thin bark. Most stems are killed by fire (Jones and DeByle 1985), which in turn stimulates suckering from the roots. Death of the stems alters hormonal balance in the trees, and the light and temperature regimes at the soil surface. Aspen stands provide valuable wildlife habitat, livestock forage, watershed protection, and esthetic and recreational opportunities; thus managers want to maintain aspen as a dominant seral forest type.

Clearcutting, burning, and scarification of aspen sites in Canada caused significant increases in soil temperature at the 0- to 1-inch depth (Maini and Horton 1966a; Steneker 1974). Canopy removal by burning and harvesting treatments in other community types also resulted in significant increases in soil temperature (Ahlgren 1981; Cochran 1975; Hungerford and Babbitt 1987; Shearer 1967). Some mitigation of temperature extremes can be provided by surface slash (Edgren and Stein 1974; Hallin 1968; Shearer 1967), which shades the surface. Regrowth of vegetation also mitigates temperature increases, but the timing varies between ecosystems (Ahlgren 1981; Hungerford and Babbitt 1987). These results suggest that burning would increase soil temperature in the northern and central Rocky Mountain aspen stands, but no published results are available to indicate the magnitude of temperature increases.

The mountainous and high-elevation character of the aspen sites in the northern and central Rockies contributes to much more variability in environmental conditions than is observed in Canada or the Lake States. On some sites (for example, steep north aspects at high elevations) soil temperature may be low enough to limit suckering regardless of treatment. Zasada and Schier (1973) suggested that aspen stands in Alaska are chiefly located on southern exposures because soil temperatures are suitable for suckering. In Wyoming, daily average temperatures in July (at a soil depth of 2 inches) were seldom above 60 °F on a high-elevation lodgepole site on a broadcast-burned clearcut (Hungerford and Babbitt 1987). Because the topography and climate of this lodgepole pine (*Pinus contorta* Dougl.) site is similar to many aspen sites, the results suggest that soil temperatures may be marginal for suckering in some northern and central Rocky Mountain aspen stands.

Soil temperatures affect the formation and development of suckers (Maini and Horton 1966a, 1966b; Steneker 1974; Williams 1972; Zasada and Schier 1973). Warmer temperatures stimulate cytokinin production by the roots (Williams 1972) and may cause degradation of auxin

---

[1] Research forester located at the Intermountain Station's Intermountain Fire Sciences Laboratory, Missoula, MT.

(Schier and others 1985). Temperature influences suckering by altering the cytokinin-to-auxin ratio (Peterson 1975; Winton 1968; Wolter 1968). Once apical dominance is broken, increased soil temperatures stimulate suckering (Steneker 1974). Temperature also affects the number of suckers per root segment (Maini and Horton 1966a; Zasada and Schier 1973). Most field studies utilized maximum temperature measurements (Maini and Horton 1966a; Steneker 1974). Zasada and Schier (1973) found that low soil temperatures inhibit sucker development, which may explain the absence of aspen on cooler sites in Alaska. Maini and Horton (1966b) concluded that temperatures less than 60 °F or greater than 95 °F inhibit suckering. Zasada and Schier (1973) indicated that the diurnal change, rather than maximum, may influence suckering and low minimums may suppress suckering regardless of maximums. Published results do not make it clear how temperature influences suckering under field conditions. The relationship of temperature with hormonal balance as it interacts with clonal variability, root depth, etc., is unclear. The temperature threshold also may vary by clone (Maini 1968; Zasada and Schier 1973).

This case study reports soil temperatures in burned and unburned aspen stands at the surface to 12 inches in depth. Differences between the burned and control treatments are presented. Observed temperatures and sucker response (Brown and DeByle 1987) are discussed relative to the published suckering temperature threshold.

TEST SITE AND TREATMENT

The Manning Basin site is located in southeastern Idaho, 10 miles southwest of Afton, WY, on the Caribou National Forest. Aspect is southeast on a 40 percent slope at 7,350 feet. Before treatment the stand consisted of nearly pure aspen, with 250 stems per acre larger than 2 inches in diameter. Saskatoon serviceberry (*Amelanchier alnifolia*), evergreen ceanothus (*Ceanothus velutinus*), pachistima (*Pachistima myrsinites*), sticky geranium (*Geranium viscosissimum*), and butterweed groundsel (*Senecio serra*) are the dominant understory species. The community type (Youngblood and Mueggler 1981) is *Populus tremuloides/ Prunus virginiana* (POTR/PRVI).

Climate is continental, with cold winters and warm summers. Average annual precipitation is 25 inches, and the July average temperature is 58 °F.

The Manning Basin site was treated with prescribed fire; an adjoining unburned stand was the control. Burning occurred on September 21, 1981, and covered 300 acres (Brown and DeByle 1987). Tree boles were charred extensively and all trees were killed. This degree of char and mortality indicates a severe burn according to the Ryan and Noste index (Ryan and Noste 1985).

TEMPERATURE MEASUREMENT

Temperatures at the surface of the soil and to depths of 12 inches were measured from 1 month after burning through part of the third year following burning. Temperature sensors were installed in burned and unburned treatments having comparable exposures at the following depths:

- surface: two sensors on litter or ash
- 1-inch: one sensor in soil
- 2-inch: one sensor in soil
- 4-inch: one sensor in soil; one in aspen root
- 8-inch: one sensor in soil
- 12-inch: one sensor in soil

First a hole with one smooth vertical face was dug. Sensors were pushed horizontally into the undisturbed so on the vertical face at the proper depths. A hole the sam diameter as the sensor was drilled in an aspen root, then the sensor was inserted. When the six soil sensors were place, the hole was filled and tamped. Material that came from the surface—ash, duff, twigs, leaves, etc.—was restored to its original position. Surface sensors were placed on undisturbed litter or ash. The sensors were covered with ash or litter—just enough that the metal sensor tip was not exposed.

Thermistor beads (0.064-inch diameter) encased in 0.5- by 0.094-inch diameter stainless steel tubing were used a sensors. Six-foot lengths of shielded wire connected the temperature sensors to a junction box in each treatment. Each junction box was connected to a multichannel data acquisition system with a multiconductor cable. The data acquisition system controlled the sampling interval and recorded the temperatures on a cassette tape.

The data aquisition system recorded temperatures ever 2 hours from October 1981 through July 1984. Technicia checked the installation and operation of the system several times during each of the two operating seasons and removed data tapes in the fall and spring. New sensors were installed as necessary at the surface. Nonfunctional sensors in the soil were not replaced, to avoid disturbing the soil.

ANALYSIS

Temperatures were compared between the burned and unburned treatments using pairwise *t*-test comparisons at the 0.05 significance level for each depth. Maximum and average temperatures at the surface and average temperatures for all depths beneath the surface were used for the tests. Suckering response for the two treatments reporte by Brown and DeByle (1987) is compared to the observed maximum, average, and range of temperature. These temperature regimes and the sucker response in the burned treatment are compared to the hypothesized 60 °F temperature threshold.

SOIL TEMPERATURES AFTER BURNING

Average temperatures on the burned treatment were significantly higher than on the control at the surface and at depths from 1 to 12 inches during the summer (June through August) of year 1 (table 1). By September the differences were not significant. Temperature differences were small in the summers of year 2 and 3 and although statistically significant in some cases, the differences likel were not great enough to be biologically significant.

Table 1—Monthly average temperatures (°F) at different depths for burned (B) and unburned (UB) treatments at Manning Basin in 1982 and 1983. Values having different letters are significantly different at $p = 0.05$

	June		July		August		September	
Depth	**B**	**UB**	**B**	**UB**	**B**	**UB**	**B**	**UB**
				1982				
Surface	62a	54b	63a	59b	65a	60b	49a	50a
1 inch	54a	50b	60a	55b	57a	57a	48a	48a
2 inches	54a	50b	—	54	—	56	—	48
4 inches	52a	48b	58a	54b	57a	56b	49a	48a
8 inches	49a	46b	55a	51b	55a	53b	49a	48a
12 inches	48a	45b	55a	50b	55a	53b	50a	48b
				1983				
Surface	55a	52b	[1]57a	[1]56a	59a	60a	50a	51a
1 inch	50a	50a	—	[1]54	58	—	49	—
2 inches	—	48	[2]55a	[2]53a	58a	57b	50a	50a
4 inches	—	—	[2]54a	[2]52a	59a	56b	50a	50a
8 inches	48a	45b	[1]51a	[1]48b	56a	53b	50a	49a
12 inches	—	45	—	[1]48	56a	53b	51a	49b

[1] 18 days.
[2] 7 days.

Daily average temperatures on the burned treatment exceeded 60 °F from 0 to 17 days per month in June through August of year 1 at the 1- to 4-inch depth (table 2). On the control, daily average temperatures exceeded 60 °F for only 4 days at the 1-inch depth. Differences between treatments were greatest in July (fig. 1), when more days above 60 °F were measured than for other months (table 2).

Surface temperatures reached as high as 153 °F and exceeded 122 °F on the burned treatment for 41 days from May through August of year 1. Surface temperatures on the control reached 140 °F in May, but once the aspen leafed out maximums declined to less than 110 °F. Daily maximum temperature differences of as much as 37 °F were observed between treatments (fig. 2) for July of year 1. By year 3, dense understory vegetation and 4,500 to 15,000 suckers per acre shaded the surface. This shade reduced maximum surface temperatures on the burned treatment so they were significantly less (or not significantly different) than on the control.

Daily maximum temperatures on the burned treatment and control exceeded 60 °F on most days (June through August) at the 1- and 2-inch depths in year 1 (table 2) and frequently in years two and three. At the 4-inch depth, maximum temperatures on the burned treatment exceeded 60 °F on most days (June through August) and from 4 to 26 days (June through August) on the control. Daily maximum temperatures varied considerably by depth (fig. 3).

Minimum temperatures on the burned and control, at depths from 1 to 12 inches, ranged from 34 to 57 °F during June through August of year 1. Monthly average minimums ranged from 41 to 55 °F for the same period. In July, average monthly minimums at depths from 1 to 12 inches ranged from 52 to 54 °F in the burned treatment and 49 to 50 °F in the control.

Table 2—The number of days for June, July, and August 1982 that average and maximum temperature was greater than or equal to 60 °F, for soil depths of 1, 2, and 4 inches

	June		July		August	
Depth	**B**	**UB**	**B**	**UB**	**B**	**UB**
Average						
1 inch	6	0	17	2	2	2
2 inches	6	0	16	0	0	0
4 inches	4	0	10	0	0	0
Maximum						
1 inch	22	25	31	29	28	30
2 inches	19	22	29	26	28	30
4 inches	19	4	28	12	20	26

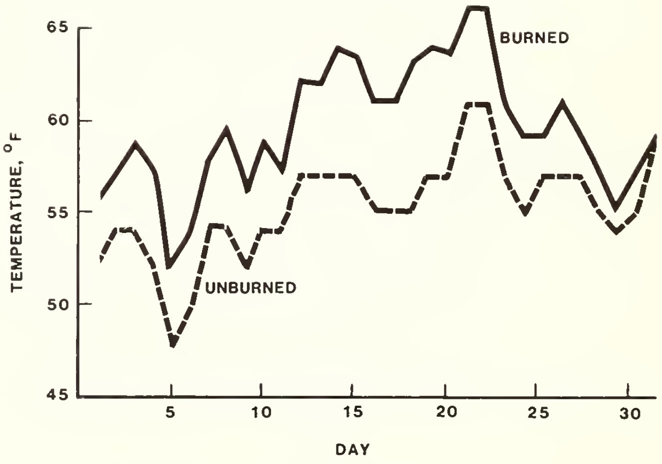


Figure 1—Daily average soil temperatures at the 1-inch depth on the burned and unburned treatments in July of 1982.

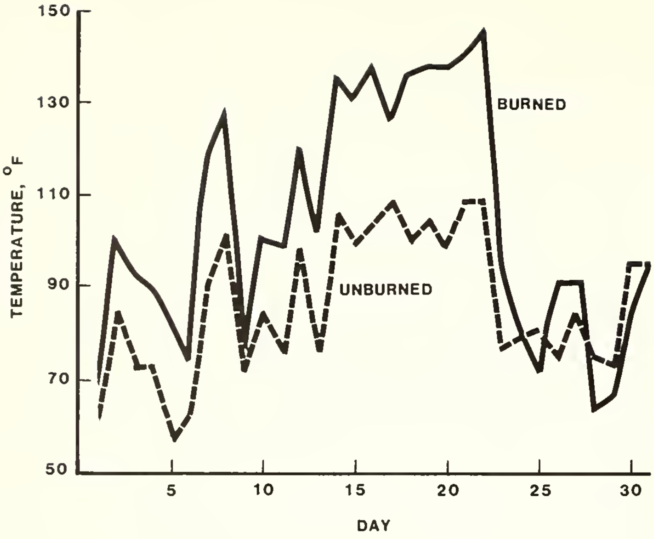


Figure 2—Daily maximum soil surface temperatures on the burned and unburned treatments in July of 1982.

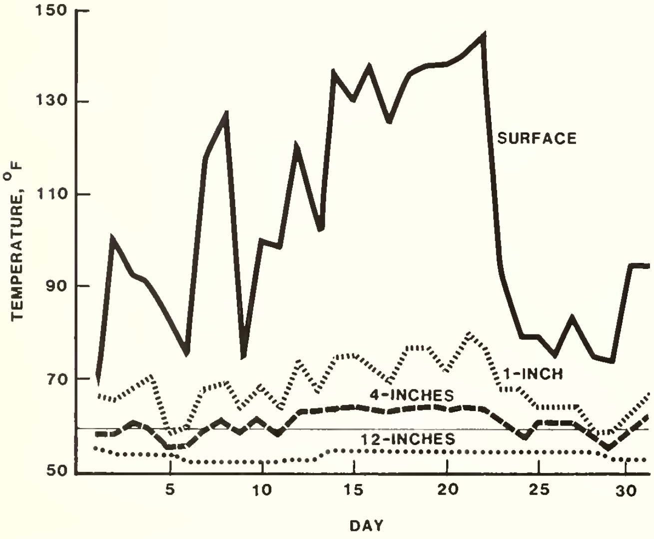


Figure 3—Daily maximum soil temperatures on the burned treatment for the surface, 1-inch, 4-inch, and 12-inch depths in July 1982.

RELATIONSHIP OF SOIL TEMPERATURE TO SUCKERING

Sucker response on the burned treatment varied from 4,500 to 15,000 suckers per acre (Brown 1986). More than 15,000 suckers per acre emerged in year 1 in a plot 300 feet from where temperatures were measured (Brown 1986). In the control, fewer than 1,000 suckers per acre emerged in year 1. The number of suckers observed is consistent with other results (Bartos and Mueggler 1982; Schier and Campbell 1980; Schier and Smith 1979), and is sufficient for reestablishing a good healthy stand of aspen. Most of the suckers (56 percent) originated from depths of 2.3 inches or less, with 91 percent from above 4.7 inches.

Maximum temperatures were above the hypothesized 60 °F threshold most of the time in year 1 (table 2). Daily average temperatures in year 1 were also above 60 °F enough that average temperatures were not limiting. Comparing the measured variable regime with Zasada and Schier's (1973) poor response at the regime of 68/50 °F, I find that maximum temperatures exceeded 68 °F on 29 days and minimum temperatures exceeded 50 °F on 60 days at the 1-inch depth. Thus all measures of temperature at this site relative to the 60 °F threshold would indicate that suckering is not limited by temperature on the burned treatment. The literature does not clearly establish whether sucker response is influenced by average temperatures, maximum temperatures, a variable temperature regime, or accumulated heat units (degree days). Maini and Horton's (1966b) laboratory results demonstrated that average temperatures of 58 °F or less reduce the initiation of suckers. In addition to temperature, other factors such as carbohydrate reserves (Schier and others 1985), clonal variability (Schier 1981), and hormonal balance (Eliasson 1971a, 1971b; Schier 1981) influence suckering of aspen. The interaction between these variables is not well understood.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The results of this study show that following prescribed burning temperatures at the soil surface to depths of 12 inches increased significantly when compared to the undisturbed stand. Rapid regrowth of understory vegetation and emergence of aspen suckers shaded the burned treatment in years 2 and 3, reducing temperatures to the level of the control. Temperature data compared to the sucker response data clearly show that, following burning, soil temperatures at depths to 4 inches were favorable for sucker initiation. Thus, these results do not provide a conclusive test for the hypothesis that temperatures less than 60 °F are limiting to suckering. Temperatures often exceeded 60 °F on the burned treatment and sometimes on the untreated area. Field experiments that limit soil temperatures to less than 60 °F while apical dominance is broken in a number of clones would provide a critical test for the 60 °F hypothesis.

The Manning Basin site is typical of many aspen stands in the northern and central Rockies. Sites with lower elevations and more southerly to westerly exposures are likely to have warmer soil temperatures than Manning Basin. Sites with warmer temperatures will not have temperature limitations to suckering. Sites with northerly exposures or at higher elevations, or both, may have lower soil temperatures than measured at Manning Basin. These lower temperatures may limit sucker initiation.

REFERENCES

Ahlgren, Clifford E. 1981. Seventeen year changes in climatic elements following prescribed burning. Forest Science. 27(1): 33-39.

Bartos, Dale L.; Mueggler, Walter F. 1982. Early succession following clearcutting of aspen communities in northern Utah. Journal of Range Management. 35(6): 764-768.

Brown, James K. 1986. Data on file for study 2108-103. On file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT; RWU 4403 files.

Brown, James K.; DeByle, Norbert V. 1987. Fire damage, mortality, and suckering in aspen. Canadian Journal of Forest Research. 17(9): 1100-1109.

Cochran, P. H. 1975. Soil temperatures and natural forest regeneration in south-central Oregon. In: Bernier, B.; Winget, C. H., eds. Forest soils and land management: Proceedings of the fourth North American forest soil conference; 1973. Quebec, PQ: Laval University: 37-52.

Edgren, James W.; Stein, William I. 1974. Artificial regeneration. In: Cramer, Owen P., ed. Environmental effects of forest residues management in the Pacific Northwest: a state of knowledge compendium. Gen. Tech. Rep. PNW-24. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: M-1—M-32.

Eliasson, Lennart. 1971a. Growth regulators in *Populus tremula.* III. Variation of auxin and inhibitor level in roots in relation to root sucker formation. Physiologia Plantarum. 25: 118-121.

Eliasson, Lennart. 1971b. Growth regulators in *Populus tremula.* IV. Apical dominance and suckering in young plants. Physiologia Plantarum. 25: 263-267.

Hallin, William E. 1968. Soil surface temperatures on cutovers in southwest Oregon. Res. Note PNW-78. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Hungerford, Roger D.; Babbitt, Ronald E. 1987. Overstory removal and residue treatments affect soil surface, air and soil temperature: implications for seedling survival. Res. Pap. INT-377. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 20 p.

Jones, John R.; DeByle, Norbert V. 1985. Fire. In: DeByle, Norbert V.; Winokur, Robert P., eds. Aspen: ecology and management in the Western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 77-81.

Maini, J. S. 1968. Silvics and ecology of *Populus* in Canada. In: Maini, J. S.; Cayford, J. H., eds. Growth and utilization of poplars in Canada. For. Branch Publ. 1205. Ottawa, ON: Canadian Department of Forestry and Rural Development: 20-69.

Maini, J. S.; Horton, K. W. 1966a. Reproductive response of *Populus* and associated *Pteridium* to cutting, burning and scarification. Dept. Publ. 1155. Ottawa, ON: Canada Department of Forestry and Rural Development, Forestry Branch. 20 p.

Maini, J. S.; Horton, K. W. 1966b. Vegetative propagation of *Populus* spp. I. Influence of temperature on formation and initial growth of aspen suckers. Canadian Journal of Botany. 44: 1183-1189.

Mueggler, Walter F. 1985. Vegetation association. In: DeByle, Norbert V.; Winokur, Robert P., eds. Aspen ecology and management in the Western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 45-55.

Peterson, R. L. 1975. The initiation and development of root buds. In: Torrey, J. G.; Clarkson, D. T., eds. The development and function of roots. New York: Academic Press: 122-161.

Ryan, K. C.; Noste, N. V. 1985. Evaluating prescribed fires. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W., tech. coords. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 230-238.

Schier, George A. 1981. Physiological research on adventitious shoot developments in aspen roots. Gen. Tech. Rep. INT-107. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Schier, George A.; Campbell, Robert B. 1980. Variation among healthy and deteriorating aspen clones. Res. Pap. INT-264. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 12 p.

Schier, George A.; Jones, John R.; Winokur, Robert P. 1985. Vegetative regeneration. In: DeByle, Norbert V.; Winokur, Robert P., eds. Aspen: ecology and management in the Western United States. Gen. Tech. Rep. RM-119. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 29-33.

Schier, George A.; Smith, Arthur D. 1979. Sucker regeneration in a Utah aspen clone after clearcutting, partial cutting scarification, and girdling. Res. Note INT-253. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 6 p.

Shearer, Raymond C. 1967. Insolation limits initial establishment of western larch seedlings. Res. Note INT-64. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Steneker, G. A. 1974. Factors affecting the suckering of trembling aspen. Forestry Chronicle. 50: 32-34.

Williams, K. R. 1972. The relationship of soil temperature and cytokinin production in aspen invasion. Albuquerque, NM: University of New Mexico. 39 p. Thesis.

Winton, L. L. 1968. Plantlets from aspen tissue cultures. Science. 160: 1234-1235.

Wolter, K. E. 1968. Root and shoot initiation on aspen callus cultures. Nature. 219: 508-509.

Youngblood, Andrew P.; Mueggler, Walter F. 1981. Aspen community types on the Bridger-Teton National Forest in western Wyoming. Res. Pap. INT-272. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 34 p.

Zasada, John; Schier, George A. 1973. Aspen root suckering in Alaska: effect of clone, collection date and temperature. Northwest Science. 47: 100-104.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

A 13.79: INT- Research Note number 379
is missing from our collection and
cannot be obtained.

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-380

April 1988

The Montana Timber Market Model—A User's Guide

William L. Wood
Patrick J. Flowers
James F. C. Hyde III[1]

ABSTRACT

The Montana Timber Market Model is a computer simulation model designed to evaluate how various harvest and log-processing scenarios will affect timber resources and economics. It covers the State of Montana or three substate regions (northwest, southwest, and central) for lands managed by the USDA Forest Service, Montana Department of State Lands, forest industries, nonindustrial private owners, and other public owners. The model provides flexibility in selecting harvest levels and other assumptions. Output consists of printed reports covering changes in timber inventory, stumpage prices, employment impacts, and other economic or inventory-related information.

KEYWORDS: supply and demand, modeling, computer simulation, timber supply projection, policy analysis

INTRODUCTION

The Montana Timber Market Model (MTMM) is an interactive computer simulation model designed to estimate future timber stumpage prices, stumpage supply and demand, timber-dependent changes in employment and income, and to monitor changes in various characteristics of Montana's timber resource. MTMM estimates are based on several assumptions, such as future harvest levels, lumber prices, production costs, starting timber inventory, growth rates, and overrun. MTMM allows the user to assess the timber resource and market implications of various management and policy options.

This user's guide describes the structure of MTMM and its use. The structure of the model is first described in general terms. This is followed by a summary of the steps required to produce a simulation. Each of these steps is then described in detail.

OVERVIEW OF MODEL STRUCTURE

The operation of MTMM can be described in five steps:

1. Initial values are assigned to all variables.
2. The interactive part allows the user to:
    a. select statewide timber processing level,
    b. select harvest level by ownership class and substate region, and
    c. inspect and/or change the default values of variables.

---

[1] William L. Wood and Patrick J. Flowers are Forest Economist and Supervisor, State Land Management Section, respectively, Montana Department of State Lands, Missoula; James F. C. Hyde III is Operations Research Analyst, formerly located at Intermountain Research Station's Forestry Sciences Laboratory, Missoula, MT.

3. Information about the starting timber inventory is automatically read into the program and adjusted according to harvest alternative selected by user.
4. A 55-year forecast period is started. During each annual iteration through the period, the following steps occur:
   a. timber harvest volume is calculated for lands managed by the Forest Service, total statewide harvest, and non-Forest Service ownership classes,
   b. the inventory volume is compared to the selected harvest strategy and the simulated harvest is reduced if inventory volume is less than the harvest specified,
   c. the simulated harvest is "transported" from origin to destination, based on 1980 log movement data,
   d. total revenue from harvesting is calculated based on stumpage price and harvested volume,
   e. timber employment and income impacts are calculated based on the substate regional harvest,
   f. the timber inventory data are adjusted to account for harvest and growth,
   g. reports are written to the output file, and
   h. economic information is updated.
5. After the simulation period is finished, the reports are summarized and the program stops.

The MTMM has both biological and economic components. The biological component contains information used to simulate timber inventory. The economic component contains information used in economic projections of market performance and features of the wood products industry. It provides information on statewide log processing levels and on the timber volume to be harvested, where, and by which ownership class, based on the selected harvest-related scenarios. The biological component uses that harvest information, adjusts the timber inventory data to reflect changes resulting from the specified harvest, and adjusts growth at the residual stand.

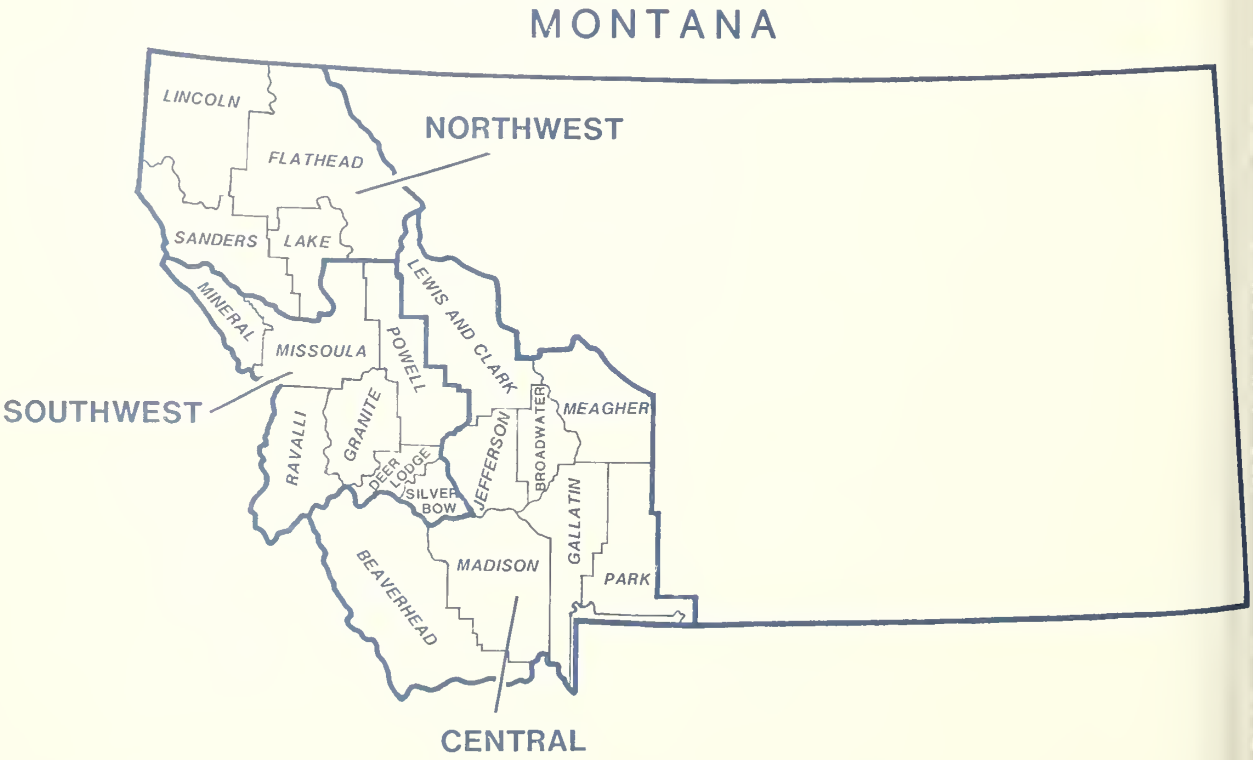


Figure 1—Multicountry regions used in study.

The following provides a more detailed look at how MTMM simulates future inventory, timber processing, timber harvest, stumpage price, and employment and income.

Inventory

The statewide timber inventory is divided into two parts. In one part inventory characteristics change over time and in the other part they remain fixed. The changing timber inventory pertains to four owner classes: Forest Service, forest industry, Montana Department of State Lands, and nonindustrial private. Each ownership class is further broken down into three geographic areas (fig. 1): northwest, southwest, and central. For each ownership class area combination, there is an inventory described in cubic feet (CUFT) by 2-inch diameter classes (6 inches to 30+ inches). These volume estimates are derived from two sources: Forest Service data are from the 1979 assessment (Laux 1986) and the non-Forest Service information from the 1979 Montana statewide inventory (Long 1986). All inventory data have been updated to 1985 based on known, historical harvest levels and estimated growth rates. The current version of MTMM does not allow the user to update the timber inventory to other years. Forest Service data were aggregated into the three geographic areas according to the percentage of each National Forest's acres in each substate region. The timber inventory is updated yearly, using growth rates by diameter class, and ownership class, and geographical area.

A portion of the statewide inventory was assumed constant, or fixed, because the available inventory data were either nonexistent or suspect. All owner/area combinations not described above were treated within the fixed component of the statewide inventory: the Bureaus of Indian Affairs and Land Management, U.S. Department of the Interior; other public, such as county or municipal owners; and all ownership in eastern Montana. This component of the inventory remains unchanged throughout MTMM simulations in that there are no yearly growth or cut updates. As a result, 16 percent of the statewide inventory is treated as fixed, while 84 percent is modeled dynamically.

The inventory accounting method can be broken down into the following steps:

1. The initial inventory is lowered to compensate for acres that are nonoperable, based on logging technologies and harvest selection.
2. The harvested volume is increased by 12 percent to account for unutilized material and growing stock lost due to logging damage (adapted from Howard and Fiedler 1984). The total harvest is distributed to diameter classes based on a "cut profile," a rule describing the percentage distribution of cut by diameter class. The harvested amount is deducted from the inventory. If the desired volume cut in a diameter class is more than the inventory available, the shortage is made up from the next lower diameter class.
3. Annual growth is calculated and added into the inventory. Also, "ingrowth" (movement from one diameter class to another) is added into the 6-inch diameter class.
4. Finally, outgrowth, the transfer of trees from one diameter class to the next larger diameter class, is performed.

Timber Processing Levels

The timber processing levels represent the targeted, annual amount of timber volume to be processed by the mills in Montana. MTMM has four methods for depicting mill processing levels: supply and demand equations, historical long-term trend, historical short-term average, and full mill capacity. The supply and demand equations are based on data from 1962 to 1985 (Connaughton 1987). Because equations are sensitive to both Forest Service harvest and non-Forest Service growing stock inventory levels, there will be a different equilibrium solution for each combination of harvest levels. The long-term trend and the short-term average processing levels were based on 15 years (1970-84) and 5 years (1980-84) of harvest data, respectively (Niccolucci 1986). The long-term trend estimates are from a regression equation; the short-term average is the mean of the five harvest estimates. Harvest data were converted into levels of timber processing for each substate region by accounting for log movements from timber-cut origin to log-processing destination. Mill capacity refers to the theoretical maximum annual volume of logs that mills could use at full production. Actual mill capacity is typically 70 to 90 percent of full capacity level. Estimates of mill capacity and log movements were obtained from the Bureau of Business and Economics Research, University of Montana (Keegan 1986).

Timber Harvest

Seven approaches were used to portray the levels of timber harvest, four related to Forest Service lands and three related to non-Forest Service. The four Forest Service alternatives are labeled "high market," "preferred," "high non-market," and "short-term average." Except for the short-term coverage, Forest Service harvest volumes were developed from information contained in the draft or final forest plans (table 1). The forest plan alternatives selected for the "high market" generally emphasize timber production while those selected for the "high non-market" generally emphasize production of amenities and other nontimber outputs. The "preferred" set consists of those alternatives identified by each National Forest as the preferred forest plan alternative. The short-term average harvest was based on 5 years (1980-84) of actual Forest Service harvests.

Timber harvest from the non-Forest Service ownership classes can be specified in three ways: "cut equals percent of inventory," "cut equals growth," and "cut equals short-term average." The calculation of the "cut equals percent of inventory" is done within MTMM by first calculating the total cubic feet (CUFT) inventory of trees greater than 8 inches d.b.h.for each non-Forest Service ownership/area class. The harvest level by ownership/area is determined by estimating the percentage that each ownership/area's sawtimber inventory comprises the total non-Forest Service harvest. If the "percentage of inventory" approach is selected, it must be used for all geographical areas (State and substate) and each non-Forest Service ownership class.

Table 1—Montana Timber Market Model Forest Service harvest specification

Alternative labels from forest plan				Percent of forest by substate region		
National Forest plan	High market	Preferred	High non-market	Northwest	Southwest	Central
Beaverhead (Final 1986)	B[1]	H	D	—	0.07	0.93
Bitterroot (Draft 1985)	A	E	J	—	1.0	—
Custer (Draft 1985)	7	6	8	—	—	.03
Deerlodge (Draft 1985)	C	M	J	—	.63	.37
Flathead (Final 1985)	2	11	16	0.80	—	.18
Gallatin (Draft 1985)	2	7	3	—	—	.86
Helena (Final 1986)	C	E	G	—	.17	.83
Lewis and Clark (Final 1986)	A	G	C	—	—	.43
Lolo (Final 1986)	C	D	J	.24	.72	—
Kootenai (Draft 1985)	L	J	F	1.0	—	—

[1] Readers interested in exact descriptions of each alternative should consult the appropriate draft or final Environmental Impact Statement for each Forest.

The last two harvest options may be mixed between owner classes and substate regions. “Cut equals growth” is calculated by summing for each owner/area the board feet (BDFT) growth across diameter classes for trees greater than 8 inches d.b.h. The ownership/area harvest is equal to total BDFT growth for each owner/area. The last non-Forest Service harvest option is “short-term average,” where harvest equals the average harvest from 1980 through 1984 for each owner/area.

Stumpage Price

When the supply and demand log processing option is selected, the equilibrium stumpage price and quantity are estimated with supply and demand equations (Connaughton 1987). When total demand exceeds selected harvest levels, the stumpage price is reestimated using the demand equation. For other timber processing options, stumpage price is estimated using the demand equation only. The demand equation requires estimates for the lumber and wood product price and manufacturing, logging, and hauling costs. Projections for these variables were produced by the Timber Assessment Market Model (Adams and Haynes 1980; Haynes 1986). All prices are expressed in 1985 dollars.

Employment and Income

All economic impact multipliers used to estimate employment and income effects come from IMPLAN (Alward and Palmer 1983), the Forest Service’s secondary data, input-output modeling system. Multipliers are backward-linked, Type II. Changes in technology and gains in production efficiency will undoubtedly change these multipliers over time, but because these changes could not be predicted, multipliers could not be updated. Individual employment and income multipliers are used for the northwest, southwest, and central regions, and eastern portion of Montana. All incomes are expressed in 1985 dollars.

CREATING AN MTMM SIMULATION

MTMM program execution can be divided into four steps:

1. Start the MTMM program and, if desired, view the general description of model and program.
2. Enter required information:
   a. Statewide timber processing levels
   b. Forest Service harvest by area (NW, SW, CTL)
   c. Non-Forest Service harvest by owner (DSL, IND, PVT) and substate regions (NW, SW, CTL)
3. Inspect and/or change, as necessary, model’s default assumptions.
4. Select desired reports, enter an output file name, and print reports after the simulation is finished.

Beginning MTMM Simulation

NOTE: In this user’s guide, the outlined area represents screen output written by the computer. A screen refers to a menu or a page of writing that is written to the computer terminal. The symbol “☛” designates the user-provided response for the question, to be followed by pressing the “Return” key. Throughout this guide, reference will be made to the “Return” key on the computer keyboard; depending on the keyboard, this key may be labeled “Carriage Return,” “Enter,” “New Line,” and so on.

Once execution has started (that is, PC user typing "MTMM" followed by a "Return" or Data General user typing "X MTMM" followed by a "New Line"), the following will appear on the screen:

```
                              MTMM

                   Montana Timber Market Model

     This software was developed through a cooperative research agreement
     between the U.S. Forest Service, Intermountain Research Station, and
     the Montana Department of State Lands and remains as public property
     and belongs in the public domain.


                 Original programming James D. Cook, 1982
                    Revised James F.C. Hyde III, 1986
                  Current revision William L. Wood, 1988

                   (Timber inventory updated to 1985.)



             The user is encouraged to study the user guide.

       Press the "Return" ("Enter" or "New Line") key to continue.
```

The second screen contains the following statements:

```
Enter code:
   1) To view introductory information about MTMM
   2) To enter Required Information, starting with timber processing levels
>> 2
```

The user selects "1" to view the opening screens that describe how to run the program and the basic structure of the model. First-time users should select "1". The user should enter "2" to start creating an MTMM simulation.

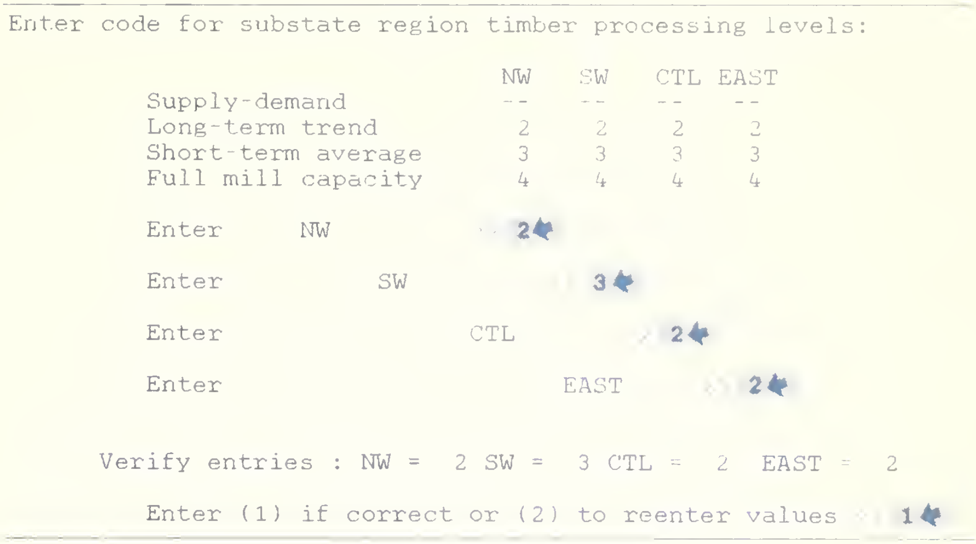
Entering Required Information

When the user selects the code "2" on the second screen, MTMM responds with a series of questions that must be answered to produce a simulation. The user must specify: statewide timber processing level, Forest Service harvest level, and finally non-Forest Service harvest level.

Statewide Timber Processing Levels—There are four methods available for specifying the processing levels—supply and demand equations, long-term trend, short-term average, and full mill capacity. The user will see and respond to the following screen next:

```
                 REQUIRED INFORMATION

Enter code for statewide timber processing level:
       1) Supply-demand model
       2) Other (long-term trend, short-term average
          or full mill capacity)
>> 2
```

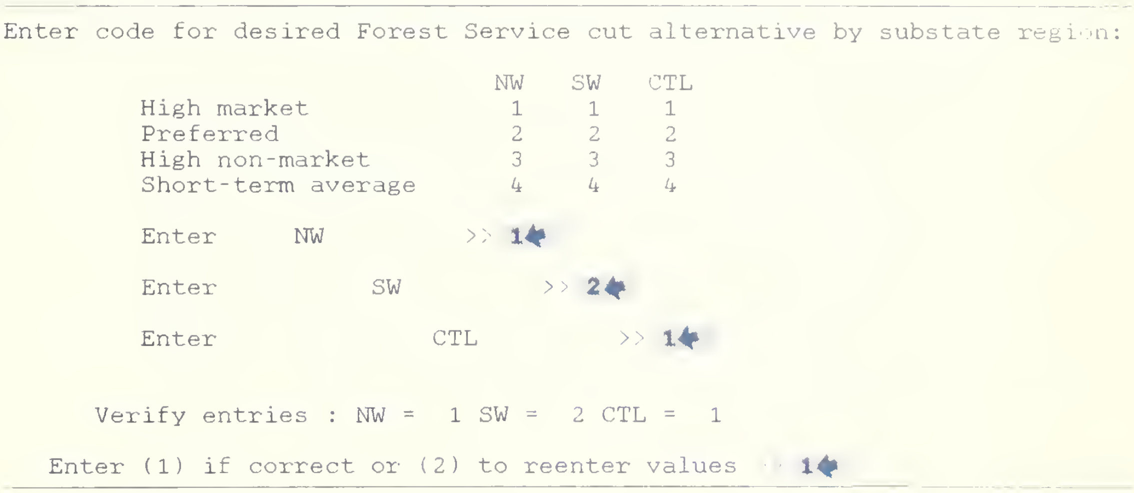
If the user selects "1", the supply and demand model approach will be used to estimate statewide and regional processing levels. If "2" is selected, then processing levels are individually selected for each region and the following appears on the screen:



```
Enter code for substate region timber processing levels:

                                NW    SW    CTL  EAST
          Supply-demand         --    --    --    --
          Long-term trend        2     2     2     2
          Short-term average     3     3     3     3
          Full mill capacity     4     4     4     4

          Enter      NW         >> 2

          Enter            SW         >> 3

          Enter                  CTL        >> 2

          Enter                        EAST       >> 2

      Verify entries : NW =   2 SW =   3 CTL =   2   EAST =   2

          Enter (1) if correct or (2) to reenter values >> 1
```

After the user enters the required timber processing information, the values selected will be relisted on the screen. The user is asked to verify the previously entered values. If these values are correct, respond with "1". If the user wishes to reenter the desired processing levels, select "2". Once a "1" is entered, the next screen will appear and the user will be asked to enter Forest Service harvest levels.

Forest Service Harvest—The Forest Service harvest options are labeled "high market," "preferred," "high non-market," and "short-term average." Alternatives are specified for each of the substate regions. The user must respond to the following:



```
Enter code for desired Forest Service cut alternative by substate region:

         NW    SW    CTL
          High market             1     1     1
          Preferred               2     2     2
          High non-market         3     3     3
          Short-term average      4     4     4

          Enter      NW         >> 1

          Enter            SW         >> 2

          Enter                  CTL        >> 1

      Verify entries : NW =   1 SW =   2 CTL =   1

   Enter (1) if correct or (2) to reenter values >> 1
```

Once again the user selects "1" to move on to the next screen, selecting non-Forest Service harvest, or "2" to reenter Forest Service harvest options. Timber harvested from Forest Service land in the eastern portion of Montana is constant over time and is added to the total harvest level for the East.

Non-Forest Service Harvest—There are three options for determining the non-Forest Service harvest level: percentage of inventory, cut equals growth, and short-term average. The following will appear:

```
Enter desired Non-Forest Service statewide cut alternative:
       1) Cut = percent of inventory
       2) Other (Cut = growth or cut = short-term average)
>> 2↵
```

If "1" is entered, "cut = percent of inventory," the next set of screens will not appear because this harvest option automatically applies to all regions and owners. If "2" is entered, the user must specify the harvest by each owner and substate region.

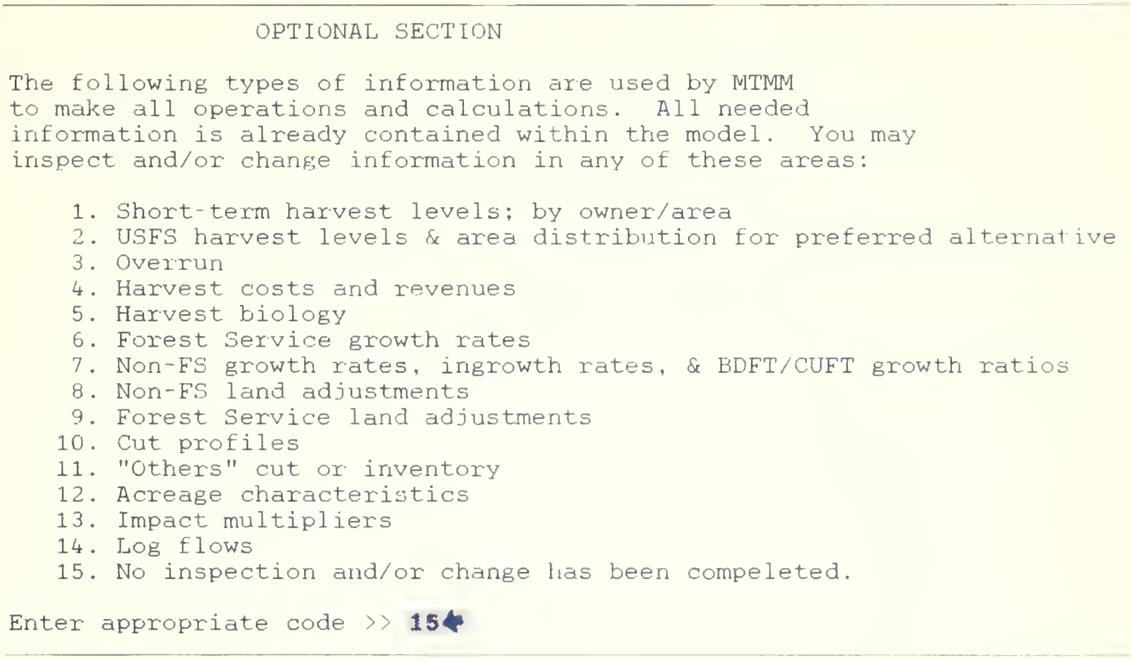
```
Enter code for Department of State Lands cut by substate region:

                                   NW    SW    CTL
     Cut = % of Inventory          --    --    --
     Cut = growth                   2     2     2
     Cut = short-term average       3     3     3

        Enter      NW          >> 2↵

        Enter           SW          >> 3↵

        Enter                CTL         >> 2↵

     Verify entries : NW =  2 SW =  3 CTL =  2

  Enter (1) if correct or (2) to reenter values >> 1↵
```

This question is repeated for all non-Forest Service owners: forest industry and nonindustrial private.

Reviewing and Changing Default Assumptions

After all required information is entered, the user has the option to inspect and/or change information describing various key assumptions within MTMM. Each assumption consists of a set of default values that will be used in all simulations, unless the user specifies different values. Each time MTMM is executed, the assumptions revert to their default values. It is important to note that MTMM does not check for extreme combinations or illogical variable values, which could cause the program to terminate execution.

The following screen will appear and gives the user the option to inspect and/or change default values:



```
                        OPTIONAL SECTION

The following types of information are used by MTMM
to make all operations and calculations.  All needed
information is already contained within the model.  You may
inspect and/or change information in any of these areas:

      1. Short-term harvest levels; by owner/area
      2. USFS harvest levels & area distribution for preferred alternative
      3. Overrun
      4. Harvest costs and revenues
      5. Harvest biology
      6. Forest Service growth rates
      7. Non-FS growth rates, ingrowth rates, & BDFT/CUFT growth ratios
      8. Non-FS land adjustments
      9. Forest Service land adjustments
     10. Cut profiles
     11. "Others" cut or inventory
     12. Acreage characteristics
     13. Impact multipliers
     14. Log flows
     15. No inspection and/or change has been compeleted.

Enter appropriate code >> 15
```

The interactive sequence for changing and/or inspecting default assumptions is:

1. If no inspection and/or change is desired, enter “15”. Otherwise, enter the number corresponding to the variable of interest and follow subsequent instructions.

2. Review the default values for the selected variable listed on the screen.

3. If the set of default values is acceptable or correct, enter “1” and return to OPTIONAL SECTION menu. If the user desires to change any of the default values, enter “2”.

4. If a “2” is entered, the variables are again listed one at a time on the screen; the respective default value is listed in the parentheses.

5. If the default value shown is correct, press the “Return” key; if a new value is desired, it should be entered.

6. Once all default values have been confirmed or revised, the screen will clear and a listing of the user-specified values, either new or default values, will appear on the screen for verification.

7. If a value was entered incorrectly, enter a “2” and reedit the variable. If the values are correct enter a “1”, return to the OPTIONAL SECTION menu, and repeat step 1.

The 14 variables that can be edited by the user are:

Variable 1: Short-Term Harvest Levels; – by Owner/Area—This allows the user to view and edit the short-term harvest levels specified for each ownership/area combination. To view or edit these values the user must have previously selected the short-term average for the desired ownership/area harvest option.

Variable 2: USFS Harvest Levels & Area Distribution for Preferred Alternative—This variable enables the user to view and edit two variables: (1) percentage distribution of National Forest timber harvest to substate regions and (2) the harvest level associated with the preferred alternative for each National Forest. To use this option the user must have previously selected the "preferred alternative" harvest option for at least one of the Forest Service substate regions. Changes are permitted in only the substate regions where the Forest Service preferred alternative option was selected. The default percentages reflect the number of acres in the substate region. These acreage estimates are the same as those used by the Forest Service to distribute the 25 Percent Fund payments to counties, the distribution of net National Forest acres within counties. If the user believes these acreages do not reflect harvest distribution, different percentages can be entered. A change in these percentages will affect only the distribution of harvest to a substate region and not the inventory. The Forest Service harvest levels are the annual harvest level from the preferred alternative for the following years—1985, 1990, 2010, and 2030. The annual harvest for years not entered is estimated by trending the harvest value at the beginning and ending of a time period.

Variable 3: Overrun—The user has two options for projecting overrun. The first option uses the default overrun projection method but allows the user to edit the default variable values. In the default method (Carr 1986; Moore 1986), overrun is trended linearly from 1.5 (or 50 percent overrun) in 1984 to 1.7 in 1994 and then to a peak of 1.8 in 2004. The maximum overrun allowed is 1.8. The second option is to enter estimates for overrun by 5-year intervals, and the program will interpolate to identify intermediate values. Overrun is only used in the supply and demand equations.

Variable 4: Harvest Costs and Revenues—This variable allows the user to change and/or view a series of economic assumptions. These include: (1) the ratio of timber volume offered for sale to volume sold for the Forest Service sales (variable affecting the supply and demand equations); (2) the estimate for the lumber and wood products price; (3) the estimate for the logging, hauling, and manufacturing cost; (4) the premium added to Forest Service stumpage price to represent non-Forest Service stumpage in 1985 dollars; and (5) the annual compound rate of increase for both lumber and wood product prices and the logging, hauling, and manufacturing costs.

Variable 5: Harvest Biology—This allows the user to edit or view a series of harvest biology assumptions. These include: (1) the annual reduction in total forest land base due to conversion of forest land to subdivision, agriculture, or other uses; (2) the estimate for the cubic-foot volume per acre of trees entering the 6-inch diameter class; (3) the number of years it takes a harvested acre to grow back into the 6-inch diameter class; (4) the number of years to reintroduce all the seedling/sapling acres back into the 6-inch diameter class; and (5) the percentage that growth rates will increase in the future because of better management practices, and the year such an increase would begin.

There are two methods to begin a permanent increase in the future growth rates. (If the user wants to increase the starting **growth** rates, go to variables 6 and 7.) In the first method, enter "% improvement in growth rates," a uniform improvement is applied to both Forest Service and non-Forest Service owners and all substate regions for the specified year. Example: If the user believes that by the year 1990 better management should increase the growth rate by 50 percent, he/she would enter a 50-percent improvement in the year 1990. The growths will increase by 50 percent and remain at that level throughout the rest of the simulation. In the second method, enter "% improvement in growth rate by owner and DBH," the user must specify the d.b.h. class, owner/area, and year to apply the improvement. Only one method for increasing growth can be used for a given simulation run. The growth rate changes specified here are applied to the default or specified values for variables 6 and 7.

Variable 6: Forest Service Growth Rates—This enables the user to edit the starting growth rate estimates for Forest Service inventory by substate region and by d.b.h. class. The default growth rates were estimated from the 1979 Forest Service assessment data.

Variable 7: Non-Forest Service Growth Rates, Ingrowth Rates, and BDFT/CUFT Growth Ratios—With this option the user can inspect and/or change the 1979 statewide inventory estimate of: (1) non-Forest Service starting growth rates by d.b.h. class and substate region, (2) ingrowth by d.b.h. class and substate region, and (3) the ratio of BDFT/CUFT for growth volume. Ingrowth is the percentage of volume growing from one diameter class into the next larger class. One set of ingrowth estimates was used for all ownerships. The ratio of BDFT/CUFT is the ratio used to convert the cubic growth into board-foot growth.

Variable 8: Non-Forest Service Land Adjustments—This allows the user to edit or review adjustment percentages for volume of timber available on non-Forest Service lands. The non-Forest Service inventory is adjusted to remove timber volumes located on land that is not available for harvesting. The default estimates reflect only physical limitations to timber harvesting and do not take into account landowners who choose to not allow timber harvesting. These percentage adjustments, however, can reflect whatever factors the user considers important.

Variable 9: Forest Service Land Adjustments—This allows the user to edit or view the Forest Service land adjustment factors. These factors vary by Forest Service harvest alternative. The adjustments were based on the suitable land base identified in the forest plan alternative divided by the acreage used in the 1979 assessment inventory. To be meaningful, land base adjustments and harvest schedules must be synchronized to a specific forest planning alternative.

Variable 10: Cut Profiles—With this variable the user may edit or view the cut profile for either the Forest Service or non-Forest Service ownership by d.b.h. class. The cut profile is used to calculate the volume removed from each d.b.h. class. The total cut profile represents the percentage distribution of timber harvest across all d.b.h. classes and therefore must sum to 1.0 (or 100 percent). The cut profile is multiplied by the owner/area harvest to calculate the volume removed from a d.b.h. class in the inventory.

Variable 11: "Others" Cut or Inventory—This variable permits the adjustment of "Others" inventory or cut. This portion of the statewide inventory ("Others") was assumed to remain unchanged because inventory data needed to simulate inventory changes was either nonexistent or suspect. The "Others" inventory consists of growing stock for the Bureau of Indian Affairs, Bureau of Land Management, and all ownerships (including Forest Service) in eastern Montana. Also, there is a growing stock variable, ADJSTK, which can be used to calibrate the supply and demand equations.

The following owner and areas have a fixed harvest level: Bureau of Indian Affairs, Bureau of Land Management, and all ownerships in the east. The Bureau of Indian Affairs harvest is further divided into northwest and southwest harvest. The Bureau of Land Management harvest is divided into southwest and central harvests. These harvests are added into the regional harvest and log delivery estimates.

Variable 12: Acreage Characteristics—This variable allows the user to edit two sets of variables. The first set is the percentage of land harvested by "clearcut" and the associated volume per acre harvested. These data are used to convert the harvest volume into acres harvested. If greater (or smaller) clearcut percentages are assumed or lower (or larger) volume per acre, the resulting acres harvested in the model will increase (or decrease). The acres harvested are returned to the inventory after 35 years (the default value) or whatever other level is specified in variable 5. The second set of variables is estimates for the number of seedling/sapling and nonstocked acres. These acres are brought back into the inventory base at the rate selected in variable 5.

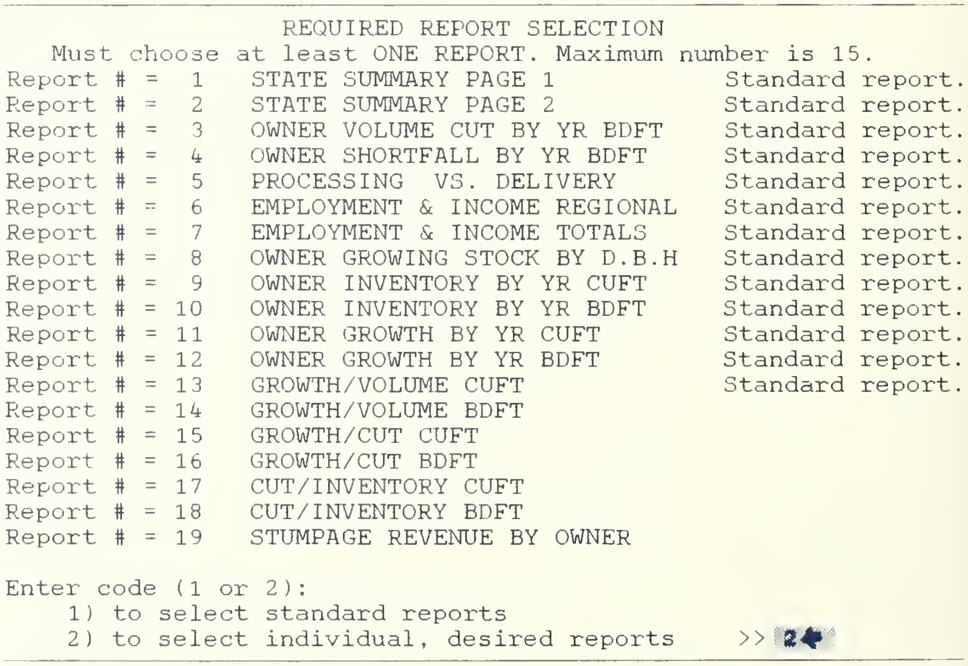
Variable 13: Impact Multipliers—This variable permits viewing or entering new estimates for income and employment impact multipliers (for the timber sector and the total economy). Unique employment and income multipliers are used for the northwest, southwest, central, and east. These figures are multiplied by the regional total for harvest to estimate the timber (direct) and total (direct + indirect) income and employment.

Variable 14: Log Flows—This variable allows the user to edit or view the log flow estimates. Log flows are the movement of logs from one geographical area (origin) to another (processing destination). The model calculates regional processing or timber deliveries by using log flow percentages and regional harvest. The log processing total for a region, such as the northwest, is a function of the percentage of timber that is cut and processed there, plus the percentage of timber cut in other regions but processed in the northwest region. There is also a percentage to account for imports into the region from out of State. Report #5 REGIONAL SUPPLY VOLUME BDFT has the regional and State total harvest adjusted for log flows. For comparison the regional and State timber processing levels are listed too.

Variable 15: No Inspection and/or Change Has Been Completed—If the user has completed or does not want to edit or inspect any of the default values, then a "15" is entered. The user then continues to the next section.

Selecting Reports

The final step the user must take to produce a simulation is to select desired output reports and enter the output file name. After completing the editing of default values, the following screen appears:



```
                         REQUIRED REPORT SELECTION
    Must choose at least ONE REPORT. Maximum number is 15.
Report # =  1   STATE SUMMARY PAGE 1           Standard report.
Report # =  2   STATE SUMMARY PAGE 2           Standard report.
Report # =  3   OWNER VOLUME CUT BY YR BDFT    Standard report.
Report # =  4   OWNER SHORTFALL BY YR BDFT     Standard report.
Report # =  5   PROCESSING  VS. DELIVERY       Standard report.
Report # =  6   EMPLOYMENT & INCOME REGIONAL   Standard report.
Report # =  7   EMPLOYMENT & INCOME TOTALS     Standard report.
Report # =  8   OWNER GROWING STOCK BY D.B.H   Standard report.
Report # =  9   OWNER INVENTORY BY YR CUFT     Standard report.
Report # = 10   OWNER INVENTORY BY YR BDFT     Standard report.
Report # = 11   OWNER GROWTH BY YR CUFT        Standard report.
Report # = 12   OWNER GROWTH BY YR BDFT        Standard report.
Report # = 13   GROWTH/VOLUME CUFT             Standard report.
Report # = 14   GROWTH/VOLUME BDFT
Report # = 15   GROWTH/CUT CUFT
Report # = 16   GROWTH/CUT BDFT
Report # = 17   CUT/INVENTORY CUFT
Report # = 18   CUT/INVENTORY BDFT
Report # = 19   STUMPAGE REVENUE BY OWNER

Enter code (1 or 2):
    1) to select standard reports
    2) to select individual, desired reports       >> 2
```

NOTE: The version of MTMM available to Data General users has no maximum report number constrain.

By entering a "1", MTMM will produce a set of "standard reports," Reports 1-13. If a "2" is entered, the following will appear:

```
Enter the desired report numbers (eg. 3,7)>> 1,3,4,10↵
```

The following is a brief summary of what is contained in each report. Monetary values found in all reports are in 1985 dollars.

Report #1: State Summary Page 1—Lists total growing stock MCF (thousand cubic feet), total growing stock MBF (thousand board feet), northwest regional harvest MBF, southwest regional harvest MBF, central regional harvest MBF, other statewide harvest MBF, and total statewide harvest MBF.

Report #2: State Summary Page 2—Lists statewide stumpage price (1985 $), statewide stumpage index (1985=100), lumber and wood products price index (1967=100), manufacturing, logging, and hauling costs (1967 $), overrun, and total statewide revenue (thousands 1985 $).

Report #3: Owner Volume Cut by Yr BDFT—Lists volume cut by owner by year in board foot Scribner.

Report #4: Owner Shortfall by YR BDFT—Lists shortfall by owner by year (MMBF [million board feet]). Shortfall occurs when the required harvest on an owner/area is greater than the inventory.

Report #5: Processing vs. Delivery—Lists the regional and State processing levels and the actual log deliveries to regions and State.

Report #6: Employment & Income Regional—Lists the estimated employment and income by region.

Report #7: Employment & Income Totals—Lists the estimated employment and income for the State.

Report #8: Owner Growing Stock by DBH—Lists the inventory in 10-year intervals by owner/area by d.b.h. class for a single year. This report is long—18 pages.

The last 11 reports are by owner, substate region, and year.

Report #9: Owner Inventory by Yr CUFT—Lists the inventory in millions of cubic feet.

Report #10: Owner Inventory by Yr BDFT—Lists the inventory in millions of board feet.

Report #11: Owner Growth by YR CUFT—Lists timber growth in thousands of cubic feet.

Report #12: Owner Growth by Yr BDFT—Lists timber growth in thousands of board feet.

Report #13: Growth/Volume CUFT—Lists the ratio of cubic-foot growth to total cubic-foot volume.

Report #14: Growth/Volume BDFT—Lists the ratio of board-foot growth to total board-foot volume.

Report #15: Growth/Cut CUFT—Lists the ratio of cubic-foot growth to the volume cut in cubic feet.

Report #16: Growth/Cut BDFT—Lists the ratio of board-foot growth to the volume cut in board feet.

Report #17: Cut/Inventory CUFT—Lists the ratio of volume cut in cubic feet to the total inventory in cubic feet.

Report #18: Cut/Inventory BDFT— Lists the ratio of volume cut in board feet to the total inventory in board feet.

Report #19: Stumpage Revenue by Owner—Lists the stumpage revenue by owner in thousands of dollars adjusted to 1985 dollars.

Once the output reports have been selected they will be listed to the screen for verification:

```
The follows reports will be produced:

Report # =  1   STATE SUMMARY PAGE 1
Report # =  3   OWNER VOLUME CUT BY YR BDFT
Report # =  4   OWNER SHORTFALL BY YR BDFT
Report # = 10   OWNER INVENTORY BY YR BDFT

Enter (1) if reports are correct or (2) to reenter reports >> 1↵
```

After desired reports are selected the program asks the user to specify an output file to which the reports will be summarized. If the user is running MTMM on a PC, the following instructions will appear on the screen:

```
Enter a "Return" to use the default output file name REPORT.LST.
(Check the DOS manual for rules about naming files.)

Enter output file name (eg. RUN123.LST) >> MTMM#7.LST↵
```

The following instructions will appear on the screen for Data General users:

```
Enter output file name        RUN19.LST↵
```

The final report will be written to the file specified, in this case called RUN19.LST. Once the output file name has been entered, the screen will clear and the following will appear:

```
MTMM RUNNING
```

When MTMM is finished running, the following message will appear on the screen:

```
****** Reports are written to a file named MTMM#7.LST   ******

                     MTMM FINISHED
```

Finally, the report file is printed with the proper print command (that is, PC = PRINT RUN 19.LST).

NOTE: Output files are formatted for wide, computer-output-sized paper.

REFERENCES

Adams, Darius M.; Haynes, Richard W. 1980. The 1980 softwood timber assessment market model: structure, projections and policy simulations. Forest Science Monograph. 22. 64 p.

Alward, Gregory S.; Palmer, Charles J. 1983. IMPLAN: an input-output analysis system for Forest Service planning. In: Seppaelae, Risto; Row, Clark; Morgan, Anne, eds. First North American conference on forest sector models: Symposium proceedings; Williamsburg, VA. Oxford: A. B. Academic Publishing: 131- 140.

Carr, William R. 1986. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Northern Region, Missoula, MT.

Connaughton, Kent. 1987. Unpublished letter on file at: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Haynes, Richard W. 1986. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Howard, James O.; Fiedler, Carl E. 1984. Estimators and characteristics of logging residue in Montana. Res. Pap. PNW-321. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.

Keegan, Charles E., III. 1986. Unpublished data on file at: University of Montana, Bureau of Business and Economics Research, Missoula, MT.

Laux, James W. 1986. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Northern Region, Missoula, MT.

Long, Brian. 1986. Unpublished data on file at: Montana Department of State Lands, Division of Forestry, Missoula, MT.

Moore, Paul. 1986. Unpublished data on file at: Montana Department of State Lands, Division of Forestry, Missoula, MT.

Niccolucci, Michael J. 1986. Unpublished data on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Missoula, MT.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-381

April 1988

Flammability Reduction Comparisons of Four Forest Fire Retardants

Aylmer D. Blakely[1]

ABSTRACT

Four commercially available forest fire retardants were studied to quantify their capabilities for flammability reduction using standard laboratory conditions and procedures. All the retardants proved to be closely matched in reducing flammability.

KEYWORDS: combustion, fire suppression, chemical retardants, fire-proofing, pyrolysis

The usefulness of forest fire retardants depends on their capabilities to control or reduce combustion of vegetation during wild and prescribed forest and range fires. When applied correctly, the retardant effectiveness depends on the reaction to heat of the basic- fire-inhibiting chemicals in the retardant formulations. The basic- fire-inhibiting chemicals in currently approved and used fire retardants are combinations of ammonium salts of sulfuric and phosphoric acids. The concentration of these chemicals usually determines the effectiveness of the formulation in retarding fire. Several other chemicals may be added to (1) increase the elasticity of the solution, (2) prevent bacterial deterioration, (3) increase the visibility of the solution when applied to the vegetation, and (4) reduce the corrosivity of the retardant solutions to exposed metals.

Some additives and/or impurities (caused by the manufacturing process) can chemically react with the retardant chemical to make compounds that are not effective fire retardants. When new retardants are formulated, their effectiveness can be predicted using their known retardant chemical content, but a decrease or increase in effectiveness caused by a combination of additives/impurities cannot be predicted. Therefore, studies are often conducted to quantify the effects of the additives/impurities and determine if any change in retardant chemical concentration is necessary to overcome these effects. The retardant effectiveness cannot be accurately predicted by analysis of total concentration of active salts, but must be quantified by burning fuels treated with the chemical formulations.

In past years when the price of chemicals was much lower, fire retardant manufacturers formulated and mixed products so that when tested they would easily exceed the USDA requirements (U.S. Department of Agriculture, Forest Service 1986[2]). Consequently, some products were slightly better than others for retarding combustion. When the price of chemicals increased (in the 1970's) and profit margins declined, retardant manufacturers began to formulate products so that only enough retardant chemical was in the formulation to meet the minimum requirements for effectiveness. The result of the more precise formulating has been to bring all approved retardants to about the same level of combustion-retarding effectiveness when tested in the laboratory.

This study was performed to quantify the fire-retarding capabilities of three presently used and one recently submitted forest fire retardants that were formulated containing enough retardant salt to meet the 0.60 superiority factor (S.F.) required in the specifications. The formulations tested are listed in table 1; their retardant salt concentrations are in table 2.[3] Because different retardant salts are not equally effective, weight for weight, table 2 has a list of retardant concentrations expressed as a diammonium phosphate (DAP) equivalency for comparative purposes. P_2O_5 was expressed as DAP by multiplying by 1.86. Monoammonium phosphate (MAP) was first converted to P_2O_5 by dividing by 1.62 then multiplied by 1.86 to determine the DAP equivalent (1.62 and 1.86 are ratios of P_2O_5 derived from the molecular weights of MAP and DAP, respectively). Because ammonium sulfate (AS) had no P_2O_5, another method was necessary to determine the DAP equivalent. From past studies (George and Blakely

---

[1] Research Forester located at the Intermountain Fire Sciences Laboratory, Missoula, MT.

[2] USDA Forest Service, Specification 5100-00304a, Section 3.7. Combustion-Retarding Effectiveness. The mixed retardant shall have a superiority factor between 0.6 and 1.0 . . . .

[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—Retardant formulations and their components

			Chemical components[1] added		
Product name	Retardant chemical	Thickener agent	Corrosion inhibitor	Spoilage inhibitor	Coloring agent
LC-A[2]	Ammonium polyphosphate	none	yes	no	yes
GTS[3]	Ammonium sulfate/ Diammonium phosphate	industrial gum	yes	yes	yes
D75[4]	Ammonium sulfate/ Monoammonium phosphate	industrial gum	yes	yes	yes
PSF[5]	Diammonium phosphate/ Ammonium sulfate	industrial gum	yes	yes	yes
MAP	Monoammonium phosphate	technical grade chemical only			
DAP	Diammonium phosphate	technical grade chemical only			
AS	Ammonium sulfate	technical grade chemical only			
AS/MAP	Ammonium sulfate/Monoammonium phosphate	combination of technical grade chemicals			

[1] For proprietary reasons, specific chemical names and concentrations are not given.
[2] Firetrol LC-A is a liquid concentrate that is diluted with 5 volumes water added to 1 volume of concentrate.
[3] Firetrol GTS is formulated as a dry powder; it is mixed 1.76 lb per gallon of water.
[4] Phoschek D75 is formulated as a dry powder; it is mixed 1.20 lb per gallon of water.
[5] Firetrol PSF is formulated as a dry powder; it is mixed 1.26 lb per gallon of water.

Table 2—DAP equivalent comparison

Retardant	Ammonium sulfate (AS) content	Diammonium phosphate (DAP) content	Monoammonium phosphate (MAP) content	P_2O_5 content	DAP[1] equivalent
	Percent[2]				
LC-A				7.57	14.08
GTS	13.62	1.21		.65	10.29
D75	8.33		2.77	1.71	8.73
PSF	9.84	2.28		1.23	8.84
MAP			10.38	6.41	11.92
DAP		9.52		5.12	9.52
AS	14.02				9.35
AS/MAP	9.45		3.15	1.94	9.91

[1] DAP equivalence determined on the basis of phosphate concentration for phosphate containing formulations; for sulfates, DAP equivalence determined on the basis of a 1:1.5 ratio of diammonium phosphate to ammonium sulfate equivalency.
[2] Percent chemical in solution by weight.

1972 and unpublished reports on file at the Intermountain Fire Sciences Laboratory) it has been determined that it takes 1.5 times as much AS as DAP to be equivalent in effectiveness on laboratory test fires.

Test fires were also conducted with solutions of the basic fire-retarding chemicals contained within each formulation but without the additives for color, thickness, preservatives, and inhibitors. The fires with basic chemical treatments were used as controls to compare the effects of nonretardant chemical additives and impurities.

METHODS

Fuel beds for the study were constructed, treated, burned, and monitored according to procedures that are explained in USDA Forest Service specification for long-term forest fire retardants (5100-00304a dated February 1986) and detailed by George and Blakely (1972). Fuel beds were constructed with either 6 pounds of ponderosa pine needles or 4 pounds of aspen excelsior. The beds were placed in wire trays 8 feet long by 1½ feet wide and 3 inches deep. The retardant treatments were applied from an overhead sprayer with a fan-shaped spray that uniformly coated the upper layers of the fuel. After treatment, fuels were dried until no retardant water remained (determined by periodic weighing), and the fuels reached approximately 7 percent equilibrium fuel moisture content (FMC) at 90 °F, 20 percent relative humidity. At this time, the beds were placed in a wind tunnel with controlled conditions of 5 mi/h wind, 90 °F air temperature,

Table 3—Superiority factors and retardant coverage

Retardant	Average percent reduction,1 gal/100 ft²		Average percent reduction, 2 gal/100 ft²		Average DAP equivalent, gal/ft²	Superiority factor
	pp[1]	Exc[1]	pp	Exc		
LC-A	0.409	0.600	0.589	0.829	8.67	0.607
GTS	.403	.669	.611	.769	6.40	.613
D75	.457	.560	.534	.846	5.56	.600
PSF	.389	.683	.532	.769	5.54	.593
MAP	.387	.704	.549	.839	7.11	.620
DAP	.422	.593	.486	.810	5.69	.578
AS	.338	.619	.532	.703	5.88	.548
AS/MAP	.474	.676	.582	.868	6.21	.650

[1] pp is ponderosa pine needles; Exc is aspen excelsior.

and 20 percent relative humidity. Using this method, only the chemical effects were quantified and not the effects of water from the retardant solution or FMC. Each test fuel bed was ignited by a 3-foot-long tray that contained untreated fuel of the same type and fuel loading as the treated bed.

Flame front spread rate and total fuel weight loss while burning were monitored to determine the retardant's ability to suppress combustion. For each fire a superiority factor was calculated by determining the reduction in flame spread rate (R/S) and fuel weight loss rate (R/W) caused by treatments. Percent reduction in burning rates was calculated by comparing R/S and R/W for untreated fuel with R/S and R/W for treated beds. The test fires (two replicates of each for AS/MAP and three for all others) were conducted with two different fuels (pine needles and aspen excelsior) and two different treatment levels (1 and 2 gallons per 100 square feet (gal/100 ft²). The superiority factor was calculated by combining percent reduction from at least 12 fires for each retardant (eight for AS/MAP). A standard error of the mean was applied to the average percentage reduction for these fires at each treatment level with each fuel. Then the average reduction for each group of fires was calculated to determine the S.F. shown by all fires for a retardant (table 3).

RESULTS AND DISCUSSION

Combustion rates were measured for 130 fires in treated and untreated fuel beds. Table 3 shows the reduction in combustion rates and superiority factors for the chemicals tested. An average DAP equivalent in grams/ft² was calculated, and the actual chemical coverage levels are listed in table 2 for comparisons. Treatment levels and subsequent burning rates for different fuels and treatments are presented in the appendix, "Summary of Treatments and Superiority Factors." Also shown are the water-to-retardant mix ratios and the retardant chemical concentrations in each formulation.

The three currently approved fire retardants, LC-A, GTS, and D75 have SF's of 0.607, 0.613, and 0.600, respectively. PSF, a new retardant that is presently being studied, has a superiority factor of 0.593. LC-A effectiveness can be compared to the P_2O_5 content of technical grade MAP or DAP. It appears that some effectiveness may be lost because of the form of P_2O_5 and additives in the LC-A, as shown in earlier studies of similar polyphosphate based retardants (George and others 1977). The average coverage levels for LC-A and MAP (appendix) are about equal, but MAP (6.41 percent P_2O_5) has a slightly higher S.F. apparently because of the reasons stated previously.

GTS effectiveness can be compared to that of technical grade AS. Both retardants have equal coverage levels and about the same (14 percent) AS content. But the addition of 1.21 percent (0.65 percent P_2O_5) DAP to GTS appears to significantly improve combustion reduction and also compensate for any reduction in effectiveness that might be caused by additives in GTS.

The formulated D75 has a 3 to 1 ratio of AS and MAP, the same ratio as the technical grade AS/MAP combination. The superiority factor for D75 is lower than that for AS/MAP because of slightly lower AS and MAP concentrations, and more additives. PSF, with more AS and less P_2O_5 than either D75 or AS/MAP, has a lower superiority factor than either of them.

One unexpected result was the relatively low percentage of reduction caused by DAP and AS when used alone as compared to the higher percentage of reduction caused by combinations of DAP and AS when the DAP equivalent levels (table 3) are about equal. GTS and AS/MAP have significantly higher coverage and show a corresponding higher superiority factor. But D75 and PSF (with 3 to 1 ratios of AS to MAP) have DAP equivalent coverage almost identical to DAP and AS alone and yet have significantly higher superiority factors. More study is necessary to determine if and why synergism occurs when DAP and AS are combined.

MANAGEMENT APPLICATIONS

When a value analysis system (USDA Forest Service 1984) is used to select a fire retardant at a retardant base, one of the criteria is retardant effectiveness. Effectiveness is weighted as 50 percent or more of the total evaluation. Effectiveness is composed of seven elements: line length, wind drift, penetration, coverage, recovery, flammability reduction, and visibility. All seven of these elements are weighted separately for use in the rating process and may be weighted differently for each different retardant.

Results of this study illustrate how closely all the currently approved retardants for aerial delivery match in flammability reduction ability. No one currently approved retardant is significantly superior to any other when tested in the laboratory under the same conditions and procedures. Therefore, all currently approved retardant formulations should be rated equally for flammability reduction, and the other effectiveness elements can be weighted discriminately to decide the final effectiveness score.

REFERENCES

George, Charles W.; Blakely, A. D. 1972. Effects of ammonium sulfate and ammonium phosphate on flammability. Res. Pap. INT-121. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 26 p.

George, C. W.; Blakely, A. D.; Johnson, G. M.; Simmerman, D. G.; Johnson, C. W. 1977. Evaluation of liquid ammonium polyphosphate fire retardants. Gen. Tech. Rep. INT-41. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 54 p.

U.S. Department of Agriculture, Forest Service. 1984. Long-term fire retardant value analysis guidelines. Washington, DC: U.S. Department of Agriculture, Forest Service, Aviation and Fire Management.

U.S. Department of Agriculture, Forest Service. 1986. Specifications for long-term retardant. Forest Service Aircraft and Ground Application Specification 5100-00304a. Washington, DC. 27 p.

APPENDIX: SUMMARY OF TREATMENTS AND SUPERIORITY FACTORS

Retardant chemical: LC-A

Specific gravity: 1.082 Mix Ratio: 5 water/1 concentrate volume

Chemical in solution (%): P_2O_5 7.57;

								Superiority factor			
	Treatment applied			Rate of		Rate of		Each	Each group		
Date	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	g/bed	g/ft²	Ft/min	Percent	g/min	Percent				
					Ponderosa pine needles						
1981	0.99	485	6.10	1.29	0.400	176	0.438	0.419			
	0.99	485	6.10	1.28	.405	192	.387	.396	0.397	0.022	0.012
	0.97	479	6.03	1.25	.419	209	.332	.376			
	1.91	936	11.78	0.75	.651	170	.457	.554			
	2.01	987	12.42	0.77	.642	136	.565	.604	.573	.027	.016
	1.91	937	11.79	0.76	.647	164	.476	.562			
			Untreated	2.15		313					
					Aspen excelsior						
1981	1.02	502	6.32	2.18	.497	188	.605	.551			
	1.02	500	6.29	1.60	.630	245	.485	.558	.577	.039	.023
	1.02	503	6.33	1.48	.658	197	.586	.622			
	2.16	1,060	13.34	0.66	.848	84	.824	.836			
	2.01	989	12.44	0.53	.878	114	.761	.820	.817	.021	.012
	2.03	995	12.52	0.67	.845	122	.744	.795			
			Untreated	4.33		476					
	1.50	738	9.29				Averages	=	0.591		0.016
									+0.016		
							Superiority factor		0.607		

APPENDIX (Con.)

Retardant Chemical: GTS

Specific Gravity: 1.099 Mix Ratio: 1.76#/gallon water

Chemical in Solution (%): Ammonium sulfate 13.62; Diammonium phosphate 1.21

								Superiority factor			
Date	Treatment applied			Rate of		Rate of		Each	Each group		
1985	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
Apr 8	1.02	510	6.30	1.20	0.381	194	0.273	0.327			
	0.98	488	6.03	1.28	.340	196	.266	.303	0.359	0.077	0.044
Apr 11	0.90	451	5.57	0.84	.497	168	.394	.446			
Apr 8	2.09	1,044	12.90	0.50	.742	147	.449	.596			
Apr 11	1.97	985	12.17	0.53	.683	126	.545	.614	.595	.028	.016
Apr 11	1.97	984	12.16	0.59	.647	138	.502	.575			
Apr 8			Untreated	1.94		267					
Apr 11			Untreated	1.67		277					
					Aspen excelsior						
Apr 9	0.99	494	6.11	1.33	.706	219	.437	.572			
	1.01	506	6.25	1.14	.748	159	.591	.670			
Apr 10	1.00	500	6.18	0.76	.791	172	.580	.686	.642	.062	.027
May 5	0.98	487	6.02	1.36	.700	254	.455	.578			
	0.98	490	6.06	1.27	.720	146	.687	.704			
Apr 9	2.05	1,023	12.64	0.83	.817	184	.527	.672			
Apr 10	2.02	1,008	12.45	0.58	.841	146	.643	.742	.735	.059	.034
Apr 10	1.95	972	12.01	0.50	.863	116	.717	.790			
Apr 9			Untreated	4.53		389					
Apr 10			Untreated	3.64		410					
May 5			Untreated	4.53		466					
	1.50	747	9.23					Average =	0.583		0.030
									±0.030		
								Superiority factor	0.613		

APPENDIX (Con.)

Retardant Chemical: D75

Specific Gravity: 1.071 Mix Ratio: 1.20#/gallon water

Chemical in Solution (%): Ammonium sulfate 8.33; Monoammonium phosphate 2.77

Date	Treatment applied			Rate of		Rate of		Superiority factor			
								Each	Each group		
1981	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
				Ponderosa pine needles							
3/2	0.94	458	4.20	1.01	0.502	188	0.455	0.479			
3/3	1.04	507	4.65	1.19	.414	199	.423	.419	0.434	.039	.023
3/4	1.05	508	4.66	1.14	.438	217	.371	.405			
3/3	2.05	995	9.12	0.85	.571	195	.435	.508			
3/4	2.10	1,020	9.35	0.87	.581	176	.490	.531	.525	.015	.009
3/4	2.08	1,010	9.26	0.85	.562	175	.493	.537			
			Untreated	2.03		345					
				Aspen excelsior							
3/3	1.15	558	5.12	2.50	.413	218	.588	.501			
3/3	1.07	520	4.77	1.91	.552	190	.641	.597	.519	.071	.041
3/4	1.13	551	5.05	1.97	.538	328	.380	.459			
3/3	2.07	1,006	9.22	0.54	.873	99	.833	.853			
3/3	2.07	1,007	9.23	0.56	.869	109	.794	.832	.840	.011	.006
3/4	2.14	1,039	9.52	0.54	.873	107	.798	.836			
			Untreated	4.26		529					
	1.57	765	7.01				Averages =		0.580		0.020
									+0.020		
							Superiority factor		0.600		

Retardant Chemical: PSF

Specific Gravity: 1.076 Mix Ratio: 1.26#/gallon water

Chemical in Solution (%): Ammonium sulfate 9.84 ; Monoammonium phosphate 2.28

Date	Treatment applied			Rate of		Rate of		Superiority factor			
								Each	Each group		
1986	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
12/15	0.90	441	4.45	1.63	0.432	231	0.364	0.398			
12/16	1.04	506	5.11	1.82	.257	235	.294	.276	0.351	0.065	0.038
12/17	1.03	505	5.10	1.35	.386	205	.369	.378			
12/15	1.98	967	9.77	1.24	.568	167	.540	.554			
12/16	2.01	982	9.92	1.27	.482	190	.429	.456	.504	.049	.028
12/17	2.11	1,032	10.42	1.13	.486	157	.517	.502			
12/15			Untreated	2.87		363					
12/16			Untreated	2.45		333					
12/17			Untreated	2.20		325					
					Aspen excelsior						
12/15	0.94	459	4.64	2.22	.583	198	.574	.579			
12/16	1.05	511	5.16	1.75	.679	174	.613	.646	.645	.066	.038
12/17	1.03	504	5.09	1.40	.703	128	.716	.710			
12/15	2.14	1,045	10.75	0.85	.841	163	.649	.745			
12/16	2.13	1,044	10.54	0.92	.832	194	.569	.701	.744	.043	.025
12/17	2.12	1,037	10.47	0.65	.862	130	.711	.787			
12/15			Untreated	5.33		465					
12/16			Untreated	5.46		450					
12/17			Untreated	4.71		450					
	1.54	753	7.61					Averages =	0.561		0.032
									+0.032		
							Superiority factor		0.593		

APPENDIX (Con.)

Retardant Chemical: MAP

Specific Gravity: 1.054 Mix Ratio:

Chemical in Solution (%): Monoammonium phosphate 10.38;

	Treatment applied								Superiority factor		
								Each fire	Each group		
Date 1985	Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction		Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
4/19	0.91	434	3.75	1.46	0.324	176	0.328	0.326			
4/19	0.98	470	4.07	1.24	.426	159	.393	.410	0.362	0.043	0.025
4/19	1.02	488	4.22	1.46	.324	164	.374	.349			
4/22	2.07	990	8.56	0.96	.556	146	.579	.568			
4/22	1.97	941	8.14	1.20	.417	149	.571	.494	.527	.038	.022
4/22	1.95	930	8.04	1.05	.514	165	.524	.519			
4/19			Untreated	1.78		262					
4/22			Untreated	2.16		347					
					Aspen excelsior						
4/17	0.96	459	3.97	1.40	.685	173	.601	.643			
4/18	0.95	454	3.93	1.24	.726	203	.556	.641	.673	.054	.031
4/18	0.98	470	4.07	0.87	.808	154	.663	.736			
4/17	2.22	1,059	9.16	0.50	.887	126	.710	.799			
4/17	2.00	956	8.27	0.53	.881	107	.753	.817	.823	.027	.016
4/18	1.96	938	8.40	0.44	.903	73	.800	.852			
4/17			Untreated	4.44		434					
4/18			Untreated	4.53		457					
	1.50	716	6.19					Averages =	0.596		0.024
									±0.024		
							Superiority factor		0.620		

APPENDIX (Con.)

Retardant Chemical: DAP

Specific Gravity: 1.061 Mix Ratio: ____

Chemical in Solution (%): Diammonium phosphate 9.52; ____

Date	Treatment applied			Rate of		Rate of		Superiority factor			
								Each	Each group		
1985	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
5/13	0.88	424	3.36	1.40	0.310	193	0.350	0.330			
	0.95	458	3.63	1.55	.236	204	.313	.275	0.361	0.105	0.061
5/14	1.10	529	4.20	1.10	.427	146	.531	.479			
5/13	1.93	930	7.37	1.13	.443	175	.411	.427			
5/14	1.98	952	7.55	1.20	.375	152	.511	.443	.460	.045	.026
	2.01	967	7.67	1.01	.474	141	.547	.511			
5/13			Untreated	2.03		297					
5/14			Untreated	1.92		311					
					Aspen excelsior						
5/9	1.01	485	3.85	1.47	.682	207	.581	.632			
5/10	0.99	477	3.78	2.76	.369	214	.572	.471	.546	.081	.047
	0.92	442	3.51	1.79	.500	216	.568	.534			
5/9	2.06	991	7.86	0.54	.883	109	.779	.831			
	1.98	953	7.56	0.81	.825	159	.678	.752	.787	.040	.023
5/10	2.07	996	7.90	0.66	.816	129	.742	.779			
5/9			Untreated	4.62		494					
5/10			Untreated	3.58		500					
	1.49	717	5.69				Averages =		0.539		0.039
									±0.039		
							Superiority factor		0.578		

APPENDIX (Con.)

Retardant Chemical: AS

Specific Gravity: 1.084 Mix Ratio:

Chemical in Solution (%): Ammonium sulfate 14.02;

								Superiority factor			
Date	Treatment applied			Rate of		Rate of		Each	Each group		
1985	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
3/29	1.03	505	5.90	1.17	0.378	194	0.324	0.351			
	1.07	526	6.14	1.37	.344	225	.297	.321	0.320	0.032	0.018
	1.02	502	5.87	1.50	.282	226	.294	.288			
3/28	2.03	1,001	11.70	0.98	.479	156	.456	.468			
	2.05	1,011	11.81	1.03	.452	166	.421	.437	.492	.070	.040
	2.12	1,041	12.16	0.86	.589	144	.550	.570			
3/28			Untreated	1.88		287					
3/29			Untreated	2.09		320					
					Aspen excelsior						
3/26	1.01	495	5.78	2.22	.583	232	.470	.527			
3/27	0.95	465	5.43	1.42	.704	177	.558	.631	.588	.054	.031
	0.99	488	5.70	1.67	.652	176	.560	.606			
3/26	2.11	1,037	12.12	0.81	.848	207	.527	.688			
	2.09	1,030	12.03	0.88	.835	180	.589	.712	.693	.017	.010
3/27	1.92	947	11.06	0.79	.835	191	.523	.679			
3/26			Untreated	5.33		438					
3/27			Untreated	4.80		400					
	1.53	754	8.81				Averages =		0.523		0.025
									+0.025		
							Superiority factor		0.548		

APPENDIX (Con.)

Retardant Chemical: AS/MAP

Specific Gravity: 1.082 Mix Ratio: ____________

Chemical in Solution (%): Ammonium sulfate 9.45 ; Monoammonium phosphate 3.15

Date	Treatment applied			Rate of		Rate of		Superiority factor			
								Each	Each group		
1981	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
				Ponderosa pine needles							
Feb.	1.00	493	5.18	1.30	0.360	182	0.472	0.416			
	0.97	477	5.01	1.10	.458	176	.490	.474	0.445	0.041	0.029
	2.19	1,078	11.32	.72	.645	166	.519	.582			
	1.92	944	9.91	.80	.606	154	.554	.580	.581	.001	.001
			Untreated	2.03		345					
				Aspen excelsior							
	1.00	490	5.15	1.16	.728	199	.624	.676			
	1.06	520	5.46	1.51	.646	185	.650	.648	.662	.020	.014
	2.03	998	10.48	.44	.897	87	.836	.867			
	2.05	1,005	10.55	.51	.880	114	.728	.804	.836	.045	.032
			Untreated	4.26		529					
	1.53	751	7.88					Average =	0.631		0.019
									±0.019		
							Superiority factor		0.650		

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-382

June 1988

Relative Suitabilities of Regression Models in Electronic Analysis of Riparian Vegetation

Rodger L. Nelson
Charles K. Graham
William S. Platts[1]

ABSTRACT

By regressing actual green vegetation weights against capacitance meter outputs, the linear model more frequently explained a greater proportion of the variance in vegetation weights than did the logarithmic model. Examination of the residual plots, however, indicated that there may often be a problem of nonconstant variance. While the linear model should ordinarily be used for predictions of green vegetation weights, sometimes a more extensive analysis is necessary to determine the appropriate model. The R^2 *values and Furnival's Index indicated a better fit for the logarithmic model. Comparisons using* R^2 *values and Furnival's Index should be used cautiously.*

KEYWORDS: herbage meter, linear, logarithmic, nonconstant variance

Increases in labor costs are continually increasing the need to develop less labor-intensive means of conducting analyses of rangeland vegetation. One device that has recently gained widespread attention for this purpose is the electronic capacitance meter, which allows quick, efficient, and nondestructive estimation of forage production (or biomass) based on the direct relationship between vegetation weight and capacitance (Fletcher and Robinson 1956; Neal and Neal 1973). These meters are simple to use, allow rapid sampling of an area because only a small, separate sample of representative vegetation need be clipped and weighed, and are useful under a variety of rangeland conditions (Currie and others 1973; Morris and others 1976; Neal and others 1976; Platts and Nelson 1983).

Use of the electronic capacitance meter depends upon the relationship between vegetation weights (green or dry weight) and electronic capacitance as measured by the meter. Double-sampling techniques (Cochran 1963) have been used to establish a relationship between the small clipped and weighed secondary samples and the unweighed primary sample. A linear regression model has typically been used to describe the relationship between vegetation weight and electronic capacitance and has generally provided an adequate description (Back and others 1969; Neal and Neal 1973; Platts and Nelson 1983). Recently, some researchers (Terry and others 1981) have suggested that taking a logarithmic transformation of both vegetation weight and electronic capacitance and fitting a linear regression model to these transformed variables may result in increased precision. This model is nonlinear in the original units and will be referred to as the logarithmic model, whereas the model using untransformed variables will be referred to as the linear model.

Much of the work supporting use of the logarithmic model consists of a comparison of coefficients of determination (R^2), a questionable procedure whose indiscriminate use is discouraged by many writers. Draper and Smith (1981), for example, state that adjusted R^2 values (adjusted for different degrees of freedom) may be used to compare equations from different sets of data, but only as an initial gross indicator. Rodriguez (1982) states that caution should be used in judging the explanatory power of a nonlinear fit when transformations are involved. Additionally, most studies were conducted in limited areas on similar vegetation, precluding evaluation of their generality.

We have successfully used electronic capacitance meters in riparian vegetation since 1979 and have assembled an extensive data base from a variety of geographic and riparian settings in the Intermountain West and under

---

[1] The authors are with the Intermountain Research Station. Rodger L. Nelson, biological technican, and William S. Platts, research fisheries biologist, are at the Forestry Sciences Laboratory in Boise, ID. Charles K. Graham, statistician, is at Ogden headquarters.

extremely variable climatic conditions. This data base was used to examine the relative merits of the two models, one using untransformed variables and the other using logarithms of both variables. Comparison of these regression models will help (1) determine the relative precision of each for estimating vegetation weights from meter readings, (2) determine which is the more generally applicable relationship, and (3) help investigators choose the more appropriate model under local conditions.

STUDY AREAS AND METHODS

We conducted herbage meter studies in three river drainages in south-central Idaho, two in northeastern Nevada, and two in northeastern and south-central Utah. The study areas in Idaho were in forested meadows of the Rocky Mountain Forest Province (Bailey 1980) and were characterized by well-developed riparian zones. The study areas in Nevada and Utah were in the Great Basin on the perimeter of the Intermountain Sagebrush Province (Bailey 1980) and were characterized by narrow, poorly developed riparian zones into which xerophytic vegetation has frequently invaded.

Sampling in the Idaho study areas almost exclusively included riparian vegetation, chiefly willows (*Salix* spp.), sedges (*Carex* spp.), and tufted hairgrass (*Deschampsia intermedia*). When nonriparian vegetation reached the water's edge, we included in the samples such species as Idaho fescue (*Festuca idahoensis*) and timber danthonia (*Danthonia intermedia*). Because riparian zones in the Great Basin study areas were relatively narrow, such terrestrial species as cheatgrass (*Bromus tectorum*) and big sagebrush (*Artemisia tridentata*) were frequently included in the sample with the typical riparian willows, sedges, and grasses. No attempt was made to determine the actual species composition of the samples. The above merely describes the difference in character between the geographic locations.

We measured sample plots using either a Neal Electronics[2] Model 18-2000 or 18-3000 electronic capacitance herbage meter. We determined vegetal capacitance of each sample plot by taking the average of three successive readings on the plot. Vegetation included in the sample was selected to provide a wide distribution of capacitance-weight points for fitting the regression models. The overall sample design was a double-sampling scheme (Cochran 1963) and is discussed in detail in Platts and others (1987) and Platts and Nelson (1983). Sample size varied with the size of the primary sample, with approximately one weighed sample plot for every four or five biomass sample plots.

Green vegetation weights (in grams) were regressed against meter readings (dimensionless) according to the linear model:

$$Y = a_1 + b_1X \qquad (1)$$

where:

Y = predicted green vegetation weight
X = meter reading
a_1 = intercept
b_1 = slope

and according to the logarithmically transformed model:

$$\text{Ln}(Y) = a_2 + b_2\text{Ln}(X) \qquad (2)$$

where:

$\text{Ln}(Y)$ = natural log of predicted green weight
$\text{Ln}(X)$ = natural log of meter reading
a_2 = intercept of the transformed data model
b_2 = slope of the transformed data model.

Zero points, corresponding to calibration of the machine to no-yield conditions, were eliminated in both regressions. This represents a departure from usual methods (Platts and Nelson 1983).

The primary measure used to assess the relative precision of each regression model for describing the relationship between meter readings and vegetation weights was the sum of the squared deviations from regression (SSD). These were calculated by determining the values from each predictive model, subtracting these predicted values from the actual values, and squaring the differences. Finally these squared differences were added to obtain a total for each sampled area. This is a natural measure of how well a model can predict, and we feel it is the most informative and appropriate.

Calculating SSD was straightforward for the linear model, but the logarithmic model required a retransformation back to the original units. A direct retransformation by antilogs results in biased estimates, and we used a correction formula recommended by Baskerville (1972) to correct this bias. (This correction was not large, however, and the results from the direct retransformation produced similar results.) The smaller the sum of squared deviations from regression, the better the fit.

The residuals were also examined to determine whether one of the assumptions of linear model fitting was violated, namely the assumption of constant variance. This was done by plotting the residuals against the predicted values. If the variance was not constant, it was expected to increase as the green vegetation weight became larger. Consequently, the plots of the residuals from the untransformed data were examined to determine if the absolute value of the residuals increased for larger values of predicted green vegetation weights. The plots obtained from the transformed model were compared with the plots from the untransformed model to determine if the residuals were more uniform throughout and also to see if the absolute values of the residuals in the transformed model decreased as the expected values increased. If they did decrease, then transformations actually caused a nonconstant variance to occur when it was approximately constant before transformation.

Other comparisons of the two models included here are (1) coefficients of determination, R^2, and (2) Furnival's Indices (Furnival 1961). These are included only because they have been widely used by other researchers and it is

---

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

of interest to evaluate the validity of these methods. Coefficients of determination do not directly measure the fit of the regression relationship to the data. Rather, they measure the proportion of variation in the response variable that can be attributed to its regression on the explanatory variable. Consequently, higher R^2 values indicate a better explanation of variation in the response variable, but comparison of R^2 values from models having different dependent variables (even when the difference results from transformation) is discouraged.

Furnival's Index (I) is an attempt to allow comparisons of residual errors among regression models when the dependent variables differ. It adjusts the standard errors to facilitate these comparisons. From the linear model, I is identical to the standard error of estimate, but from the logarithmic model, I is calculated as:

$$I = (S_{Y \bullet X}) \times (e^Y) \qquad (3)$$

where:

$S_{Y \bullet X}$ = the standard error of estimate

e^Y = the antilog of the natural logarithm of the mean vegetation weight.

As with standard errors of the estimate, lower values of I indicate a better fit between the model and the observed data.

Neither R^2 nor Furnival's Index directly measures how well a model predicts.

RESULTS

Results of the study indicate a need for careful consideration of the merits of each model before making a selection of their use.

Sums of Squared Deviations

An examination of the sums of the squared deviations from the regression model showed a clear superiority of the linear model over the logarithmic model. The data from the locations in Idaho resulted in 40 out of 52 (or 77 percent) linear regressions having a lower SSD than the logarithmic regressions. In the more arid regions of Utah and Nevada, the results were even more favorable for the linear model. Here 23 out of 27 (or 85 percent) linear regressions resulted in lower SSD than using the logarithmic model. Contingency table analyses of these results indicate significantly more favorable results ($p<0.01$) for the linear model in both geographic regions.

Residual Plots

The results from the examination of the residual plots were ambiguous. Admittedly, examining these plots was somewhat subjective, and more data points from some locations would have helped. Nevertheless, 25 out of 52 locations in Idaho appeared to produce more uniform residual plots. In the Great Basin this number was 12 out of 27. Thus, in almost half of the cases, the log transformation seemed to help correct for nonconstant variances. On the other hand, in over half the cases it appeared that a correction was unnecessary. This ratio was about the same in Idaho as in the more arid locations in the Great Basin.

Coefficients of Determination

When the R^2 values were examined, there were only 12 out of 52 (or 24 percent) cases in Idaho where the linear model had higher R^2 values than the logarithmic model. This is opposite of what was found by examining the sums of squared deviations. In the Great Basin, however, 15 out of 27 (or 50 percent) showed higher R^2 values for the linear models. (Mean values are presented in table 1.) However, the differences in the means of the coefficient values were not found to be significant. The logarithmic model appeared to provide the better fit in Idaho based on this criterion, whereas the linear model seemed more suitable in the Great Basin sites. There also appeared to be a difference in fit that was related to the year of sampling.

The proportion of logarithmic R^2 values exceeding the linear R^2 values was tested to determine if this value differed from 0.5. The proportion of cases in Idaho was significantly greater than 0.5 ($p<0.01$), but the proportion of cases in the Great Basin was not significantly different from 0.5 ($p<0.05$). It should be recalled that comparison of R^2 values for different dependent variables is discouraged and that these were made for comparison with the work of other researchers. Nevertheless, the results of the R^2 values were opposite of what was expected after examining the SSD for both locations, and particularly for locations in Idaho.

Table 1— Mean linear and logarithmic model coefficients of determination (R^2) by geographic region and year of sampling

Study areas	Mean R^2											
	1979		1980		1981		1982		1983		Total	
	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log	Lin	Log
Idaho	0.70	0.78	0.83	0.84	0.74	0.82	0.86	0.89	0.74	0.86	0.78	0.84
Great Basin	.90	.69	.83	.83	.81	.78	.85	.87	.78	.80	.83	.80
Combined	.76	.75	.83	.84	.77	.81	.86	.88	.76	.84	.79	.83

Table 2—Mean linear and logarithmic model values of Furnival's Index (*I*) by geographic region and year of sampling

Study areas	Mean *I* 1979 Lin	1979 Log	1980 Lin	1980 Log	1981 Lin	1981 Log	1982 Lin	1982 Log	1983 Lin	1983 Log	Total Lin	Total Log
Idaho	33.9	20.0	20.0	13.5	27.7	21.7	33.2	25.8	25.4	17.4	27.9	19.6
Great Basin	15.6	19.2	43.3	34.0	7.2	8.2	29.2	16.6	28.2	19.4	24.2	28.3
Combined	28.7	19.8	26.2	19.0	20.4	16.9	31.6	22.0	26.4	18.1	26.6	19.2

Furnival's Index

Furnival's Index (1961) has also been used by other researchers to compare models (Terry and others 1981). The purpose of this index (*I*) is to adjust the standard errors of regression models with different dependent variables to allow comparison among them. The model producing a lower value of *I* would be interpreted as the model that best fits the data.

The results from this index were more dramatically in favor of the logarithmic model than were comparisons of R^2. In Idaho 42 out of 52 (or 81 percent) produced higher indices for the logarithmic model, and in the Great Basin only 18 out of 27 (or 67 percent). Again, these results were unexpected after examining the SSD values.

Also of interest is the fact that Furnival's Index indicated that the transformed model was better 13 times in 79 cases. However, we found no evidence from the SSD's, residual plots, or the scatter diagrams of the original data to support this result.

Table 2 shows average values of *I* for both regression models by year and geographic location. Overall values of *I* were significantly lower ($p<0.001$) when data were fitted to the logarithmic model. In only two cases did the linear model produce lower *I* values: Great Basin in 1975 and 1981. It is interesting that these two exceptional incidents occurred in the more arid Great Basin study areas, and during two unusually dry years.

DISCUSSION

For most of the conditions under which we have used the electronic capacitance meter with double-sampling, the linear regression model provided a more accurate means of predicting green weights based upon the SSD. Each squared deviation measures how far the predicted value deviates from the observed value, and their sum provides an overall measure of how far the model predictions deviate from observed values. The sum of squared deviations from the regression model is a clear, natural, and powerful measure of how well the model predicts and was considered as the overriding criterion for determining which regression model provided better predictions.

However, the assumption of a uniform variance is also extremely important in model fitting. Examination of the residual plots indicated that this was a problem in about half the cases that we examined. A logarithmic transformation of the data can sometimes be used to help correct this problem. Our results are thus somewhat ambiguous, and it may often be difficult to determine which model should be used. Under ordinary circumstances, when a quick prediction of vegetation weight is wanted, we see little advantage in using the logarithmic model because it is more complicated conceptually and more difficult to compute. In addition, when transformations are used, direct retransformations result in biased predictions requiring the use of correction factors.

In some situations an extensive analysis to determine the appropriate model may be justified. Under these circumstances we recommend a careful examination of the data using scatter plots of both the data and the residuals as well as examination of the SSD. It may be important to determine what transformation corrects for a nonconstant variance, and after transformation if a linear model fits the transformed data, or if a nonlinear model is indicated. This procedure can become rather complicated and will not be discussed at length here.

Interestingly, the linear model worked better in arid regions than in wetter areas and in drier years. On the other hand, the logarithmic model produced its best results in wetter regions and in wetter years. Thus, weather conditions may influence the shape of the curve and influence the choice of the more appropriate model.

Investigators should always retain the responsibility of comparing the fit of both models to their data and selecting the more appropriate one.

Comparison of coefficients of determination (R^2) derived from each model is not a recommended procedure because the dependent variables are not identical. This method has often been used, but our results verify that it is nothing more than a rough indicator. Even so, we expected the R^2 values to produce the same general results as the sums of the squared deviations. When the magnitudes of the R^2 values were examined, however, they showed no clear-cut superiority for the logarithmic model, although the logarithmic model produced higher values of R^2 more frequently. Thus, based on the comparison of R^2 values, we would have little reason to reject use of the linear model for most routine analyses.

An examination of the values obtained from Furnival's Index implied a clear superiority of the logarithmic model over the linear model. This was a result of the magnitudes of the *I* values as well as the fact the *I* values were generally lower for the logarithmic model. Again we expected Furnival's Index to produce the same results as the SSD, and our results were surprising. These results—and the 13 cases where Furnival's Index indicated a transformation and other analyses indicated a transformation was unnecessary—suggest a careful reexamination of routine use of this index.

The question of the significance of sampling riparian vegetation needs further evaluation. Vegetation moisture may likely have an effect on the relative suitability of the two models because the logarithmic model tended to be more effective in the wetter study areas of Idaho. Certainly, this would indicate that plant phenology may have a bearing on model selection, as may the range type (for example, riparian or upland range). We are currently considering studies that will help answer these questions. Meanwhile, the choice of which model to use requires careful thought and analysis.

REFERENCES

Back, H. L.; Adler, F. E.; Gibbs, B. G. 1969. An evaluation of a electronic instrument for pasture yield estimation. Part 2. Use with double sampling for pasture yield estimation. Journal of British Grassland Society. 24: 168-172.

Bailey, R. G. 1980. Description of the ecoregions of the United States. Misc. Publ. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 77 p.

Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forest Research. 2: 49-53.

Carpenter, L. H.; Wallmo, D. C.; Morris, M. J. 1973. Effect of woody stems on estimating herbage weights with a capacitance meter. Journal of Range Management. 26: 151-152.

Cochran, W. G. 1963. Sampling techniques. 2d ed. New York: John Wiley and Sons. 413 p.

Currie, P. O.; Morris, M. J.; Beak, D. L. 1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 2. Sown ranges. Journal of British Grassland Society. 28: 155-160.

Draper, N. R.; Smith, H. 1981. Applied regression analysis. 2d ed. New York: John Wiley and Sons. 709 p.

Fletcher, J. E.; Robinson, M. E. 1956. A capacitance method for estimating forage weight. Journal of Range Management. 9(2): 96-97.

Furnival, G. M. 1961. An index for comparing equations used in constructing volume tables. Forest Science. 7: 337-341.

Morris, M. G.; Johnson, K. L.; Neal, D. L. 1976. Sampling shrub ranges with an electronic capacitance instrument. Journal of Range Management. 29: 78-81.

Neal, D. L.; Neal, J. L. 1973. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 1. History and development. Journal of British Grassland Society. 28: 81-88.

Neal, D. L.; Currie, P. O.; Morris, M. J. 1976. Sampling herbaceous native vegetation with an electronic capacitance instrument. Journal of Range Management. 29(1): 74-77.

Platts, W. S.; Armour, C. A.; Booth, G. D.; [and others]. 1987. Methods for evaluating riparian habitats with application to management. Gen. Tech. Rep. INT-221. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 177 p.

Platts, W. S.; Nelson, R. L. 1983. The electronic capacitance meter: a tool for evaluating riparian-fishery habitat. North American Journal of Fisheries Management. 3: 219-227.

Rodriguez, R. N. 1982. Correlation. Encyclopedia of Statistical Sciences. 2: 193-204.

Terry, W. S.; Hunter, D. H.; Swindel, B. F. 1981. Herbage capacitance meter: an evaluation of its accuracy in Florida rangelands. Journal of Range Management. 34: 240-241.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Jnited States
epartment of
griculture

orest Service

Intermountain
Research Station

Research Note
INT-383

June 1988

SCREEN(F): A FORTRAN77 Program to Identify Predictors of Dichotomous Dependent Variables

David A. Hamilton, Jr.[1]

ABSTRACT

The computer algorithm described by Hamilton and Wendt (1975), which screens potential predictor variables of a dichotomous dependent variable, has been rewritten in FORTRAN77. This note describes changes introduced in the FORTRAN77 version of the program, updates the original user's guide, and describes program availability and hardware requirements for running the program.

KEYWORDS: data screening, logistic regression, modeling, computor algorithm, statistical method

Analytical procedures that effectively screen potential relationships when the dependent variable is continuous may not be appropriate or as effective when the dependent variable is dichotomous. Hamilton and Wendt (1975) described a computer algorithm specifically designed to screen potential relationships between a set of independent variables and a dichotomous dependent variable. The theory upon which this algorithm is based was described by Sterling and others (1969).

The algorithm was originally programmed as two PL/1 procedures by Malcolm Glesser in PL/1 48-character set. Hamilton and Wendt (1975) modified the procedures, discussed properties and potential uses of the algorithm, and prepared documentation and a user's guide for the procedures.

Because the procedures were written in PL/1, their use has been limited to those individuals who have access to a PL/1 compiler. Thus some potential users have been unable to use the algorithm. When I attempted to recompile the procedures on the two latest releases of the PL/1 compiler, I encountered what appear to be compiler bugs. The procedures apparently compile successfully but will not execute a test problem correctly.

These problems provided the motivation to rewrite the procedures in FORTRAN77. The new program, SCREEN(F), eliminates the problems encountered when the old procedures were compiled under the latest releases of the PL/1 compiler and the need to have access to a PL/1 compiler. This latter fact greatly increases the number of potential users who will be able to run the program on their computer system.

UPDATES OR MODIFICATIONS TO THE ALGORITHM

There are only a few minor differences between SCREEN(F) and the program documented by Hamilton and Wendt (1975). The original program permitted unlimited numbers of independent variables. When SCREEN(F) is used, the analysis is limited to 50 potential independent variables. If this limitation creates problems for a user, additional independent variables may be evaluated by making multiple runs of the program or by increasing the dimension of the variables NCTG, VN, VNS, INDEX, IPVAR, ISUB, INA, and DUMMY in the source code of the main program and subroutine GRAPH.

The PL/1 version of this program was written as two PL/1 procedures. The first procedure (SEARCH) consisted of the screening algorithm. The second procedure (GRAPH) printed the results of the screening in a "decision tree" format. The two procedures were either run independently or linked together with job control language (JCL).

SCREEN(F) is written as a single program. The main program contains what was in the PL/1 procedure SEARCH. The GRAPH procedure is now a subroutine

---

[1] Research forester located at Intermountain Station's Forestry Sciences Laboratory, Moscow, ID.

```
                    STATISTICS CONTROLLING VARIABLE SELECTION

                                                 NODE
 VARIABLE          1      2      3      4      5      6      7      8      9     10
DATASET NUMB     0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
FOREST CODE      0.00   0.00   0.00   0.00   2.68   3.29   6.23   0.00   0.00   0.00
REGEN.SYSTEM     1.65   2.95   0.00   0.00   6.01   0.00   6.73   0.00   0.00   0.00
HABITAT TYPE     0.00   0.00   0.00   0.00  10.69   0.00   0.00   0.00   0.00   0.00
ASPECT           2.18   0.00   3.02   0.00   4.63   3.32   0.00   0.00   3.07   0.00
SLOPE PERCNT     1.74   0.00   0.00   0.00   2.81   0.00   2.29   0.00   0.00   1.61
TOPO.POSIT'N     0.00   0.00   3.53   0.00   4.81   0.00   0.00   0.00   0.00   0.00
SITE PREP.       0.00   0.00   3.17   0.00   0.00   3.05   2.49   0.00   2.80   2.77
SEED SOURCE      0.00   0.00   0.00   0.00   0.00   1.98   0.00   0.00   2.21   0.00
ANGLE 2 SEED     0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
R.BASAL AREA     0.00   3.39   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
ELEVATION        1.96   0.00   0.00   0.00   5.26   0.00   3.72   3.62   2.08   2.10
TIME             6.28   0.00   0.00   0.00   8.46   0.00   3.07   0.00   2.34   2.06
REGEN. MODE      0.00   0.00   0.00   0.00   5.54   2.74   4.82   0.00   0.00   0.00
STOCKING         0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
DEFOL.BEFORE     1.38   0.00   0.00   0.00   2.54   0.00   3.49   2.85   0.00   0.00
DEFOL.AFTER      3.81   0.00   3.45   1.89   5.28   1.42   0.00   0.00   1.85   0.00
```

Figure 1—Example of SCREEN output showing a table of statistics used in variable selection process.

called from the main program. This eliminates the need to use JCL to link the two components of the program. Further, the duplication of control input data required in the PL/1 version of the program has been eliminated. The only input that must be supplied to the GRAPH subroutine by the user is the title that is to be used as a page header for the "decision tree" diagram. The remaining control input data required for GRAPH is now passed as arguments in the subroutine CALL statement. Details of the control input data required to run SCREEN(F) are provided in the "Updated User's Guide" section of this note.

SCREEN(F) prints one new type of output that I have found useful in interpreting the results of the algorithm. A table is printed that contains values of the test statistic used to determine which independent variable is selected at each node in each of the first three levels of the "decision tree." The statistic is an entropy statistic that is distributed approximately as chi-square. The value printed in the table has been adjusted for differences in degrees of freedom. The statistic and the adjustment procedure are described in detail in Sterling and others (1969). If the statistic is not significant at the user-specified significance level, a value of zero is printed in the table.

Although the statistics are dependent on which variables have been selected at previous nodes, at any specified node the statistics for each of the independent variables are independent. Thus they provide the user with information about which independent variable would have been selected at each node if the originally chosen variable had been eliminated from the analysis. This information is particularly useful when two or more of the variables being considered explain approximately equal amounts of the remaining variation. Previously, the only method available to evaluate what would happen when a variable was removed from the analysis was to rerun the analysis with that variable deleted. Although complete analysis of a set of data may still require that selected variables be removed from the analysis and the program rerun, the new output provides information that is very useful in structuring successive runs of SCREEN and thus frequently reduces the number of runs that are required to complete an analysis.

Figure 1 presents an example of this new output. Each of the nodes in the first three levels of the "decision tree" are labeled with a number enclosed in brackets (fig. 2). The table reproduced in figure 1 lists the statistics used to select the most significant independent variable at each node. The statistics for node 1 are in the first column of numbers in figure 1. The largest number in this column is the value 6.28 for the variable "TIME", the variable selected at node 1. The second largest value is 3.81 for the variable "DEFOL.AFTER". Thus, if "TIME" were removed from the analysis, it would be replaced at this node by "DEFOL.AFTER". Similar interpretations should be given to the values in the other columns of the table. Note that there is only one nonzero value in the column for node 4. This implies that there are no other significant independent variables at this node and if the selected variable, "DEFOL.AFTER", is removed from the analysis, the node will be dropped from the "decision tree."

UPDATED USER'S GUIDE

Most of the instructions for using the screening algorithm remain unchanged from what was presented by Hamilton and Wendt (1975). In this update of the user's guide, only those instructions that are different will be discussed.

The input data set is now read on logical unit 2. The requirements for the format of the observations making up the input data set have not been changed. Each independent variable can occur at one of eight levels, coded 0 to 7. The dependent variable is coded as either 0 or 1. Finally,

```
CREEN OF ESTABLISHMENT DATA -- COMBINED DATA.


       TIME
      [ 1] 1,2,3YRS
           4+5YEARS
           ........
           .    20.
           .    15.
           ........
           6+7YEARS
           ........
           .    30.
           .     1.
           ........


                     R.BASAL AREA
                    [ 2] NONE
                         10SQ.FT.
                         20SQ.FT.
                         ........
           8+9YEARS      .    33.
           ........      .    35.
           .    61.      ........
           .    41.      30-40
           ........      50-70
                         80-100
                         110-180
                         190PLUS
                         ........
                         .    28.
                         .     6.
                         ........


                                   SITE PREP.
                                       NONE
                                       MECH
                                       ........
                     TOPO.POSIT'N      .    18.
                    [ 3] BOTTOM        .    45.
                         LOWER         ........
                         MIDSLOPE      BURN
                         ........      ROADCUT
                         .    35.      ROADBED
                         .    51.      ROADFILL
                         ........      ........
                                       .    17.
                                       .     6.
                                       ........
```

igure 2—Sample of SCREEN "decision tree" output
howing nodes in first three levels identified by
umbers enclosed in square brackets.

t is no longer required that the logical record length of the nput data set be equal to the number of variables in each bservation.

Data for program control are input on logical unit 5 on ix types of records in the main program. These records orrespond to the six card types discussed by Hamilton nd Wendt (1975). Record types 2, 3, 5, and 6 are identical o card types 2, 3, 5, and 6. On record type 1, the variables RECL and INPT have been deleted. The two remaining variables on this record are NVAR (number of variables) and NLR (number of observations). The format of this new record type 1 is 2I6. As in the PL/1 version of the program, if the product of NVAR and NLR is greater than 32,676, the input data set must be read and processed one observation at a time from logical unit 2 for each node in the "decision tree." This is necessary to avoid exceeding the dimensions specified for the input array. If the product is less than 32,676, the input data set is read only once and stored in an array. A new feature of SCREEN(F) is that the the appropriate method of data input is now determined by the program. SCREEN runs much more efficiently when the data are read only once into an array. Thus, although the user can no longer control the method of data input with the variable INPT, some care should be taken in determining the size of the data set to be analyzed. If a data set is larger than the limit that permits the data to be read only once, it may be advantageous to select a subset of the data for analysis that is smaller than the limit.

Record type 4 is similar to card type 4 with the variable NTOTAL deleted. The remaining variable names on the record have been converted to integer variable names, and the format for the record is 3I6. On several of the record types, some variable names have been changed in the source code to correspond to FORTRAN naming conventions. Variable type (for example, real or integer) for these variables remains as it was documented by Hamilton and Wendt (1975).

Because GRAPH is now a subroutine, much of what was previously read on input control cards is now passed in the subroutine argument list. All the control data that remain to be read in GRAPH is the variable TITLE, which is now read from record type 7. TITLE is declared CHARACTER*80. Thus, the format for record type 7 is A80.

Results of the data screening are passed from the main program to the GRAPH subroutine on a scratch file. The scratch file is written on logical unit 8.

To make multiple runs of the algorithm using the same input data set, it is only necessary to prepare record types 3 to 7 for the second and each succeeding run. There is an additional advantage to making multiple runs with SCREEN(F) that did not exist in the PL/1 version. If the data set is small enough to be stored in an array, it will be read only for the first run. This reduces the time the program spends doing input/output operations and thus reduces elapsed execution time.

HARDWARE REQUIREMENTS AND PROGRAM AVAILABILITY

SCREEN(F) has been run on the IBM 3090[2] at Washington State University, on a Data General MV 15000, and on IBM PC's. On the IBM 3090, the program was compiled using version 4.0 of the IBM FORTRAN VS compiler. On the Data General MV 15000, the program has been run under AOS/VS using the F77 FORTRAN compiler. On PC's, the program has been successfully compiled with

---

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Lahey FORTRAN, IBM Professional FORTRAN, Microsoft FORTRAN, and Ryan McFarland FORTRAN.

The executable code on the PC requires 260 K bytes. Although the program has only been run on an IBM PC AT and on an IBM PS/2 model 60, the program should run on either an IBM PC or XT or compatibles. Output files require a logical record length of 132. Thus, when run on a PC, the printer used must either be wide carriage or be capable of compressed printing.

Source code for the program is available on request from:

David Hamilton
Forestry Sciences Laboratory
1221 S. Main Street
Moscow, ID 83843

Requests should include either a 5 1/4-inch or a 3 1/2-inch floppy disk. Files provided on the disk will include source code for SCREEN(F), an example test data set of 1,000 observations (each observation made up of 17 variables), control input data needed to run the example, and output generated by the example. Executable code for a PC operating under PC/DOS or MS/DOS is also available on request.

REFERENCES

Hamilton, David A., Jr.; Wendt, Donna L. R. 1975. SCREEN: a computer program to identify predictors of dichotomous dependent variables. Gen. Tech. Rep. INT-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 20 p.

Sterling, Theodor D.; Binks, Randall G.; Haberman, Shelby; Pollack, Seymour V. 1969. Robot data screening—a ubiquitous automatic search technique. In Milton, Roy C.; Nelder, John A., eds. Statistical computation. New York: Academic Press: 319-333.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

ited States
partment of
riculture

est Service

ermountain
search Station

search Note
-384

y 1988

Plant Density and Cover Response to Several Seeding Techniques Following Wildfire

Warren P. Clary[1]

BSTRACT

Comparisons of several seeding techniques were made lowing two wildfires in central Utah. In instances where seeding techniques could be directly compared on the ne site, the most intensive seeding technique always ulted in greater density and cover of seeded grasses. In specific comparisons, aerial seeding and multiple ining were better than aerial seeding alone, drilling was ter than aerial seeding and chaining, and land imprint- was better than drilling. Because conditions on the rned area were heterogenous, many of the specific indi- lual revegetation attempts could not be directly com- red. However, generally, similar conclusions can be wn as in the paired seeding comparisons. On the rage, double chaining resulted in better stands than gle chaining, and drilling resulted in better stands than ining, although initial seeding conditions and later nd erosion caused variable results

YWORDS: revegetation, rangeland drill, land imprinter, chaining, aerial seeding

Rehabilitation of rangelands by seeding began in the stern United States in the late 1800's. More literature sts on range seeding than any other practice in range nagement (Heady 1975). However, only a limited ount of seeding information in the pinyon-juniper and gebrush zones has been published in recent years. Most hat published addresses forage species adaptation her than the issue of seeding techniques (Lavin and nsen 1975, 1977a, 1977b; Stevens 1983). Lavin and ers (1973) discussed intensive revegetation techniques h as prespraying, spraying, undercutting, plowing, face drilling, and furrow drilling, but they did not study effectiveness of less intensive techniques such as adcast seeding with chaining, cabling or railing, or adcast seeding alone. Their work showed that different nbinations of season, seedbed preparation, and planting procedure are required for best results with different plant species.

Several reports have suggested that seeding effectiveness was less with chaining than with drilling, but direct comparisons were not made (Ralphs and Busby 1978, 1979). Successful broadcast seeding appears to be most likely when precipitation is above normal and the soils are rocky (Davis 1986; Koniak 1983). Recent information on the relative effectiveness of the land imprinter versus the rangeland drill suggests the imprinter is more successful than the drill on loose seedbeds but less successful on firm seedbeds (Haferkamp and others 1985).

STUDY AREA

In July 1981 lightning ignited two major fires in the Canyon Mountains area of central Utah (fig. 1). These fires, the Clay Springs and Little Oak Creek Burns, covered over 25,000 ha in the pinyon-juniper (*Pinus* spp.-*Juniperus* spp.) and big sagebrush (*Artemisia tridentata*) vegetation types. The lands burned were predominately under Federal management—Forest Service of the U.S. Department of Agriculture and Bureau of Land Management (BLM) of the U.S. Department of the Interior.

The soils on most of the burned area were formed on alluvium from sandstone, limestone, quartzite, and igneous rocks. They varied from shallow to deep, and many had a surface soil texture of fine sandy loam. In the valley bottoms, where the prefire vegetation had been dominated by big sagebrush, the destruction of organic material by the fire was virtually complete, resulting in removal of all competing plants and debris from the soil surface. This left the soils vulnerable to wind erosion.

Revegetation efforts by the management agencies began in the fall of 1981. A variety of techniques were used depending upon site conditions, agency approach, and some special study situations. The techniques included aerial seeding, aerial seeding with single chaining, aerial seeding with double chaining (usually with a modified chain), a special case of aerial seeding with a strip of multiple chaining, rangeland drilling, and land imprinting.

---

[1] Project leader at Intermountain Station's Forestry Sciences Labora- , Boise, ID.

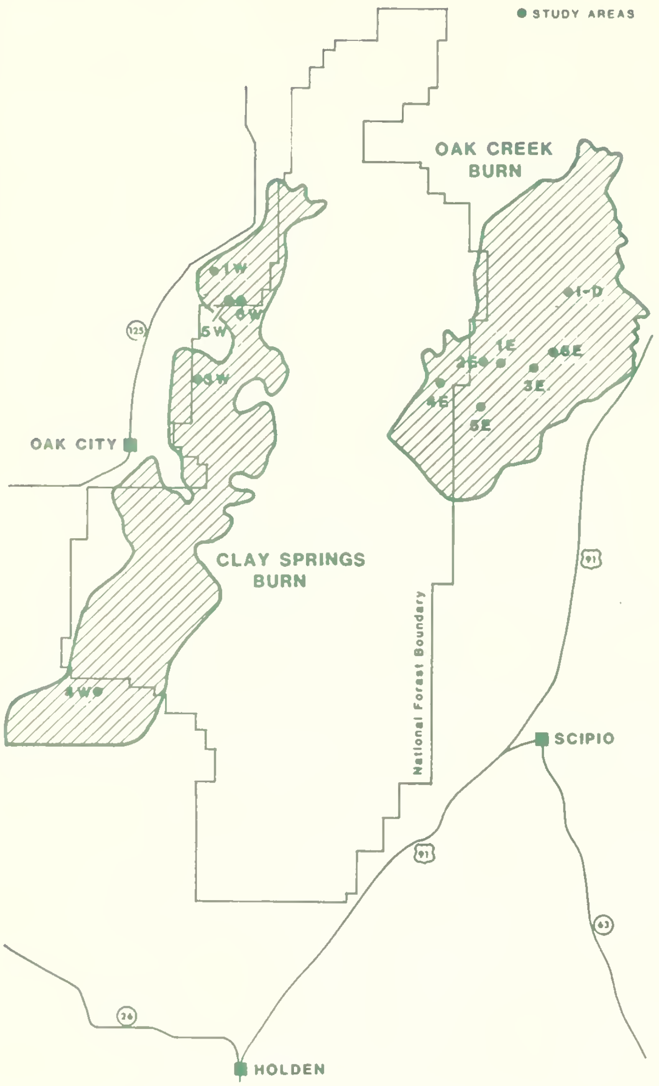


Figure 1—Location of the Canyon Mountains burns and study sites.

The implement used for imprinting was described by Johnson (1982). It included a seed box mounted to drop seed ahead of the rollers.

On the National Forest System lands, seeding was from the air at a rate of 11.3 kg/ha,which included these species (see table 1 in "Results" section for scientific names): crested wheatgrass, 3.4 kg; intermediate wheatgrass, 1.7 kg; Russian wildrye, 1.7 kg; 'Manchar' smooth brome, 1.1 kg; 'Ladak' alfalfa, 2.0 kg; small burnet, 1.1 kg; and yellow sweetclover, 0.3 kg. On areas revegetated by the BLM at the rate of 9.0 kg/ha, the amounts per seeded species were: Fairway crested wheatgrass, 4.5 kg; 'Luna' pubescent wheatgrass, 1.7 kg; Russian wildrye, 2.2 kg; and 'Ladak' alfalfa, 0.6 kg.

On BLM lands most seeding was done by drilling, although some areas were seeded from the air. In addition to the seed mix, 0.6 kg/ha of fourwing saltbush seed was applied from the air across the BLM seeding area. In several drilled locations severe wind erosion occurred due to high wind velocity, light-textured soils, and lack of cover. These areas were redrilled in 1982 with 12.2 kg/ha using the following seed mixture: crested wheatgrass, 4.5 kg; 'Luna' pubescent wheatgrass, 2.2 kg; fourwing saltbush, 1.1 kg; winter rye, 2.2 kg; yellow sweetclover, 1.1 kg; and 'Ladak' alfalfa, 1.1 kg.

Mean annual precipitation ranges from 250 to 410 mm depending upon site elevation. Precipitation for the three water-years following seeding was 160 to 172 percent of normal, based on weather records from nearby communities of Scipio and Oak City. However, rainfall the first year after seeding (1982) was only 68 percent of normal for the important April to June period. Conversely, in 1983, when a portion of the area was redrilled, the April to June precipitation was 151 percent of normal, and in 1984, when the study data were collected, rainfall for the same months was 180 percent of normal.

SAMPLING METHODS

Individual study sites were sampled by 20 to 90 transects each. The transects consisted of 10 plots of $1m^2$ each, located 3 m apart. Plant density counts were recorded for all perennial plant species within the 1-m^2 plots. Estimates of lightly compressed foliage cover (proportion of area completely covered by foliage in a manner similar to the square-foot-density method; Brown 1954) were made for all species using the following percentage categories: 0.01 to 1.0, 1.1 to 5.0, 5.1 to 25.0, 25.1 to 50.0, 50.1 to 75.0, 75.1 to 95.0, and 95.1 to 100. Standing crop biomass was also determined and reported in Clary (1987) and Clary and Wagstaff (1987). Where paired comparisons were possible, statistical analyses were conducted by t-test.

RESULTS

The plant communities present 3 years after the fires and seeding were about 80 percent grasses (table 1). On the Clay Springs Burn, a seeded perennial grass, crested wheatgrass, was the most prominent in the amount of cover while the annual cheatgrass was second. On the Little Oak Creek Burn, three perennial grasses—the seeded crested wheatgrass and intermediate wheatgrass, and the native bluebunch wheatgrass—each had greater amounts of cover than did cheatgrass. Forb composition was dominated by the seeded alfalfa and was approximately 10 percent of the plant community. The most abundant shrub on the Clay Springs Burn was broom snakeweed, while Gambel oak exceeded broom snakeweed on the Little Oak Creek Burn.

Table 1—Average plant density (number/m^2) and cover (percent) 3 years after seeding two wildfire burns

Species	Clay Springs		Little Oak Creek	
	Density	Cover	Density	Cover
GRASSES				
Crested wheatgrass (*Agropyron cristatum* and *A. desertorum*)	3.28	2.66	2.75	2.70
Thickspike wheatgrass (*Agropyron dasystachyum*)	.52	.01	.00	.00
intermediate wheatgrass (*Agropyron intermedium*)	.96	.67	1.57	1.46
Western wheatgrass (*Agropyron smithii*)	.05	T[1]	2.03	.26
Bluebunch wheatgrass (*Agropyron spicatum*)	.08	.07	1.45	1.92
Pubescent wheatgrass (*Agropyron trichophorum*)	.10	.08	.43	.46
Smooth brome (*Bromus inermis*)	.74	.40	.02	.01
Cheatgrass (*Bromus tectorum*)	—[2]	1.68	—	1.43
Russian wildrye (*Elymus junceus*)	.03	.01	.07	.05
Indian ricegrass (*Oryzopsis hymenoides*)	T	T	.12	.07
Switchgrass (*Panicum virgatum*)	T	.01	.00	.00
Bluegrass (*Poa* spp.)	.00	.00	.01	T
Sandberg bluegrass (*Poa secunda*)	.14	.01	.23	.04
Winter rye (*Secale cereale*)	—	.00	—	.00
Bottlebrush squirreltail (*Sitanion hystrix*)	.03	.02	.16	.13
Needleandthread (*Stipa comata*)	.00	.00	.03	.01
FORBS				
Pale agoseris (*Agoseris glauca*)	.00	.00	.01	T
Kings sandwort (*Arenaria kingii*)	.00	.00	.03	.01
Eureka milkvetch (*Astragalus eurekensis*)	.00	.00	.12	.03
Bastard toadflax (*Comandra pallida*)	.00	.00	.01	.03
Hairy fleabane (*Erigeron aphanactis*)	.00	.00	.07	.01
Redroot eriogonum (*Eriogonum racemosum*)	.00	.00	.10	.02
Alfileria (*Erodium cicutarium*)	—	T	—	.04
Prickly lettuce (*Lactuca serriola*)	—	.08	—	.01
Peavine (*Lathyrus brachycalyx*)	.00	T	T	.01
Heath aster (*Leucelene ericoides*)	.00	.00	.13	.07
Alfalfa (*Medicago sativa*)	.50	.61	.35	.76
Yellow sweetclover (*Melilotus officinalis*)	.00	.00	.00	.00
Rock goldenrod (*Petradoria pumila*)	.00	.00	.03	.01
Hood phlox (*Phlox hoodii*)	.00	.00	.00	.04
Russian-thistle (*Salsola iberica*)	—	.00	—	.06
Small burnet (*Sanguisorba minor*)	T	T	.01	T
Tumblemustard (*Sisymbrium altissimum*)	—	.01	—	T
Gooseberryleaf globemallow (*Sphaeralcea grossulariaefolia*)	.05	.02	.37	.04
SHRUBS				
Louisiana sagewort (*Artemisia ludoviciana*)	.00	.00	.06	.01
Big sagebrush (*Artemisia tridentata*)	.01	.02	.02	.01
Fourwing saltbush (*Atriplex canescens*)	.00	.00	.00	.00
Downy rabbitbrush (*Chrysothamnus viscidiflorus puberulus*)	.01	.02	.01	.01
Variedleaf green rabbitbrush (*Chrysothamnus viscidiflorus viscidiflorus*)	.00	.00	.01	.02
Stansbury cliffrose (*Cowania mexicana stansburiana*)	T	.04	.00	.00
Nevada ephedra (*Ephedra nevadensis*)	.01	.02	.01	.02
Utah juniper (*Juniperus osteosperma*)	T	.02	.00	.00
Pricklypear (*Opuntia* spp.)	T	.02	.02	.03
Gambel oak (*Quercus gambelii*)	.00	.00	.01	.21
Horsebrush (*Tetradymia* spp.)	.00	.00	.01	.03
Broom snakeweed (*Gutierrezia sarothrae*)	.51	1.04	.20	.16
ALL SPECIES	7.02	7.52	10.45	10.18

[1] T = trace.

[2] — = no density data for annuals.

The revegetation efforts obviously resulted in plant establishment because the herbaceous portion of the plant community was dominated by seeded plants. However, different degrees of success occurred as a result of different seeding techniques.

Perennial Plant Density

Paired revegetation treatments were compared on similar sites in three instances. Chaining following aerial seeding was more successful in establishment of seeded grasses than aerial seeding alone, drilling was more successful than chaining, and imprinting was more successful than drilling (table 2). Seeded forb densities were also greater in two of these same three treatments. No successful establishment of shrubs was detected. Native plant densities were highly variable between and within treatments and showed no significant trends. Combined densities of all perennial plants, seeded and native, were significantly higher in the more successful revegetation treatments. Therefore, increases in seeded species did not result in equivalent decreases in native perennial species.

On much of the burn where paired comparisons were not feasible, a similar trend was apparent, that is, the more intensive the planting effort the better the result. Drilling treatments were better than the chaining treatments for average establishment of seeded species on the Little Oak Creek Burn (table 3). Double chaining after aerial seeding resulted in higher seeded grass densities than did single chaining on the Clay Springs Burn although there was little difference in seeded forb densities (table 4). The variations in native plant densities appeared to be a function of their presence before the fire rather than a response to a specific revegetation effort.

Plant Cover

The cover of seeded grasses, as with plant densities, was greater for those treatments that tend to provide better seed coverage or seedbed compaction (table 5). Chaining after aerial seeding was better than aerial seeding alone, drilling was better than chaining, and land imprinting was better than drilling. A similar trend occurred for seeded forbs, but the difference was statistically significant in only one of the three comparisons. In all three comparisons, the cover of annuals was significantly higher in the less successful seeding treatments, undoubtedly the result of less competition from the seeded grasses. There did not appear to be an important variation in total plant cover within paired treatments, although one significant difference did occur.

On the unpaired sites of the Little Oak Creek Burn, the single drilled site exhibited about twice the cover and the redrilled site about 11 times the cover of seeded plants as did the chained sites (table 6). Similar to the paired treatments (above), the cover of annuals was greater where there was less establishment of seeded grasses. Little difference in total plant cover occurred among treatments. Fewer differences were present among the unpaired sites on the Clay Springs Burn compared to sites on the Little Oak Creek Burn. One double-chained site had greater

Table 2—Comparisons of perennial plant densities (number/m^2) on the Canyon Mountains burns

Plant group	Aerial seed and multiple chain vs. aerial seed (5W,6W)	Drill vs. aerial seed and single chain (1E,2E)	Imprint vs. drill (I-D)[1]
Seeded			
Grass	9.2a vs. 0.5b[2]	6.7a vs. 1.6b	4.7a vs. 2.1b
Forb	1.2a vs. .0b	.7a vs. .2a	.1a vs. .0b
Shrub	.0a vs. .0a	.0a vs. .0a	.0a vs. .0a
Native			
Grass	.2a vs. .1a	5.1a vs. 5.7a	9.5a vs. 6.5a
Forb	.1a vs. .0a	1.7a vs. 2.9a	.0a vs. .0a
Shrub	.4a vs. 1.4a	.3a vs. .4a	.0a vs. .0a
Total	11.1a vs. 2.0b	14.5a vs.10.8b	14.3a vs. 8.6b

[1] Data from Clary (1987).

[2] Data pairs within columns followed by different letters are significantly different at the 5 percent level.

Table 3—Perennial plant densities (number/m^2, x±se) on individual locations, Little Oak Creek Burn

Plant group	Drill (3E)	Drill redrill 1982 (6E)	Aerial seed and double chain (4E)	Aerial seed and single chain (5E)
Seeded				
Grass	5.4 ± 0.8	14.4 ± 1.1	1.9 ± 0.4	1.4 ± 0.7
Forb	.6 ± .1	1.1 ± .1	.0 ± .0	.0 ± .0
Shrub	.0 ± .0	.0 ± .0	.0 ± .0	.0 ± .0
Native				
Grass	.2 ± .1	1.4 ± 1.3	3.2 ± .4	1.0 ± .2
Forb	.5 ± .3	.0 ± .0	.4 ± .2	.1 ± .1
Shrub	.1 ± .1	.0 ± .0	1.1 ± .4	.8 ± .1
Total	6.8 ± 1.0	16.9 ± 1.7	6.6 ± .6	3.3 ± .7

Table 4—Perennial plant densities (number/m^2, x±se) on individual locations, Clay Springs Burn

Plant group	Aerial seed and double chain (4W)	Aerial seed and double chain (3W)	Aerial seed and single chain (1W)
Seeded			
Grass	6.6 ± 1.0	5.4 ± 0.8	3.7 ± 0.5
Forb	.1 ± .1	.3 ± .1	.9 ± .2
Shrub	.0 ± .0	.0 ± .0	.0 ± .0
Native			
Grass	2.9 ± 1.6	.4 ± .1	.6 ± .2
Forb	.0 ± .0	.0 ± .0	.1 ± .1
Shrub	.2 ± .1	1.0 ± .4	.1 ± .1
Total	9.8 ± 1.6	7.1 ± .7	5.4 ± .7

Table 5—Comparisons of compressed plant cover (percent) on the Canyon Mountains burns

Plant group	Aerial seed and multiple chain vs. aerial seed (5W,6W)	Drill vs. aerial seed and single chain (1E,2E)	Imprint vs. drill (I-D)[1]
Perennial			
Seeded			
Grass	4.2a vs. 0.2b[2]	2.7a vs. 0.6b	9.4a vs. 5.0b
Forb	1.0a vs. .0a	.9a vs. .1a	.5a vs. .2b
Shrub	.0a vs. .0a	.0a vs. .0a	.0a vs. .0a
Native			
Grass	.0a vs. .0a	5.9a vs. 5.5a	1.7a vs. 1.4a
Forb	.0a vs. .0a	.2a vs. .6b	.0a vs. .0a
Shrub	.6a vs. 3.0a	.2a vs. .3a	.0a vs. .0a
Annual	.1a vs. 1.4b	1.1a vs. 2.2b	.1a vs. .7b
Total	5.9a vs. 4.6a	11.0a vs. 9.3a	11.7a vs. 7.3b

[1] Data from Clary (1987).

[2] Data pairs within columns followed by different letters are significantly different at the 5 percent level.

Table 6—Compressed plant cover (percent, x±se) on individual locations, Little Oak Creek Burn

Plant group	Drill (3E)	Drill redrill 1982 (6E)	Aerial seed and double chain (4E)	Aerial seed and single chain (5E)
Perennial				
Seeded				
Grass	5.5 ± 1.0	11.7 ± 1.1	1.6 ± 0.5	0.8 ± 0.5
Forb	2.2 ± .5	2.1 ± .4	.0 ± .0	.0 ± .0
Shrub	.0 ± .0	.0 ± .0	.0 ± .0	.0 ± .0
Native				
Grass	.1 ± .1	.2 ± .2	4.1 ± .7	.5 ± .3
Forb	.0 ± .0	.0 ± .0	.2 ± .1	.0 ± .0
Shrub	.0 ± .0	.0 ± .0	2.6 ± 1.2	.9 ± .2
Annual	.6 ± .2	.0 ± .0	2.7 ± .7	6.1 ± 1.2
Total	8.4 ± 1.0	14.0 ± 1.2	11.2 ± 1.0	8.3 ± 1.0

Table 7—Compressed plant cover (percent, x±se) on individual locations, Clay Springs Burn

Plant group	Aerial seed and double chain (4W)	Aerial seed and double chain (3W)	Aerial seed and single chain (1W)
Perennial			
Seeded			
Grass	7.4 ± 1.2	3.8 ± 0.8	3.6 ± 0.5
Forb	.2 ± .1	.3 ± .1	1.6 ± .3
Shrub	.0 ± .0	.0 ± .0	.0 ± .0
Native			
Grass	.1 ± .1	.1 ± .1	.3 ± .1
Forb	.0 ± .0	.0 ± .0	.1 ± .0
Shrub	.5 ± .3	1.4 ± .5	.3 ± .2
Annual	1.0 ± .4	2.5 ± .9	3.9 ± 1.4
Total	9.2 ± 1.1	8.1 ± .8	9.8 ± 1.2

cover of seeded grasses and less of annuals than the single-chained site, but the second double-chained site was comparable to the single-chained site (table 7). Total plant cover was similar among sites.

DISCUSSION

Paired and unpaired comparisons between revegetation techniques generally indicated greater densities and cover of seeded plants for those revegetation practices that appeared to do a better job of seed coverage or compaction of the seedbed. This is consistent with past results (Jordan n.d.; Plummer and others 1968; Reynolds and Springfield 1953). Direct comparisons of revegetation techniques across all sites could not be made because site and situation differences were involved. For example, aerial seeding-chaining was often applied to steeper and rockier terrain with higher precipitation than was drilling or imprinting. However, in instances when drilling could be directly or indirectly compared to aerial seeding-chaining on similar sites, drilling resulted in superior stands of seeded species.

In the paired comparisons, treatments resulting in the most seeded grasses also resulted in the least annual grasses. This same trend continued through the unpaired sites. However, the presence of seeded grasses did not significantly decrease the density or cover of native perennial grasses on the paired sites, nor did the seeded grasses appear to have an effect on native perennials when viewed across the unpaired sites. Three years after the fire and the seeding effort, the amount of native perennial grasses present seemed to be primarily a function of what was present before the fire. The presence of seeded species occurred mainly at the expense of annual grasses.

The side-by-side comparison of land imprinting and rangeland drilling illustrated an approximately 2:1 advantage of density and cover of seeded species in favor of imprinting under the conditions of this study. The increased establishment of seeded species with the imprinter probably resulted in part from increased surface soil bulk density and the seed being pressed into close contact with the light-textured soil (Anderson 1981). The ratio of comparative seeding costs is $67 (imprinting): $42 (drilling) (Clary and Wagstaff 1987), which suggests that the imprinter established 25 percent more seeded plant density and cover per dollar of cost than did the drill. However, studies of herbage production on these burns showed that compensatory growth in the thinner stands of the drilling resulted in similar amounts of biomass being produced 3 years after seeding. In the case of herbage production the drilling was more efficient per dollar of cost (Clary and Wagstaff 1987).

Because costs of aerial seeding and chaining combined equaled or exceeded those of drilling or imprinting (Clary and Wagstaff 1987) and the plant establishment success was less, there appears to be little cost-efficiency justification for use of the chaining technique on sites that can be drilled or imprinted. For sites where drilling or imprinting techniques cannot be applied, careful consideration should be given to seeding expenditures. Under many conditions the success of plant establishment using the chaining technique may be too low to justify its use. Presumably, to justify the chaining technique even modest revegetation success is needed for such values as soil protection, wildlife habitat characteristics, preclusion of unwanted plants, or enhancement of visual quality (Clary and Wagstaff 1987).

In some instances where substantial amounts of native perennial grasses are present, such as occurred on study areas 1E, 2E, and 4E, there may be little necessity to incur seeding costs. Natural recovery of native perennials should provide an adequate forage resource and soil protection (West and Hassan 1985). Unfortunately, it is often difficult to predict postfire response on many sites.

REFERENCES

Anderson, R. 1981. Technology for reversing desertification. Rangelands. 3: 48-50.

Brown, Dorothy. 1954. Methods of surveying and measuring vegetation. Bull. 42. Commonwealth Bureau of Pastures and Field Crops, Hurley Berks: Commonwealth Agricultural Bureaux; Farnham Royal, Bucks, England. 223 p.

Clary, Warren P. 1987. Revegetation by land imprinter and rangeland drill in central Utah. Unpublished manuscript on file at: Forestry Sciences Laboratory, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Boise, ID; RWU 4202 files. 25 p.

Clary, Warren P.; Wagstaff, Fred J. 1987. Biological and economic effectiveness of several revegetation techniques in the pinyon-juniper-sagebrush zone. In: Everett, Richard L., compiler. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 305-312.

Davis, William F. 1986. [Personal communication.] On file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID.

Haferkamp, M. R.; Miller, R. F.; Sneva, F. A. 1985. Seeding rangelands with a land imprinter and rangeland drill in the Palouse Prairie and sagebrush-bunchgrass zone. In: Vegetative rehabilitation and equipment workshop, 39th annual report; 1985 February 10-11; Salt Lake City, UT. Missoula, MT: U.S. Department of Agriculture, Forest Service, U.S. Department of the Interior, Equipment Development Center: 19-22.

Heady, Harold F. 1975. Rangeland management. New York: McGraw-Hill. 460 p.

Johnson, Thane J. 1982. Rangeland imprinting in Utah. In: Vegetative rehabilitation and equipment workshop, 36th annual report; 1982 February 4-5; Denver, CO. Missoula, MT; San Dimas, CA: U.S. Department of Agriculture, Forest Service, U.S. Department of the Interior, Equipment Development Center: 16-17.

Jordan, Gilbert L. [No date]. Range seeding and brush management on Arizona rangelands. T81121. Tucson, AZ: University of Arizona, College of Agriculture, Agricultural Experiment Station, Cooperative Extension Service. 88 p.

Koniak, Susan. 1983. Broadcast seeding success in eight pinyon-juniper stands after wildfire. Res. Note INT-334. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Lavin, Fred; Gomm, F. B.; Johnsen, T. N., Jr. 1973. Cultural, seasonal, and site effects on pinyon-juniper rangeland plantings. Journal of Range Management. 26(4): 279-285.

Lavin, Fred; Johnsen, Thomas N., Jr. 1975. Forage shrub adaptation trials at three pinyon-juniper sites. ARS W-29. Berkeley, CA: U.S. Department of Agriculture, Agricultural Research Service. 5 p.

Lavin, Fred; Johnsen, Thomas N., Jr. 1977a. Planting site classification and longtime species adaptation in the pinyon-juniper woodland. ARS W-45. Berkeley, CA: U.S. Department of Agriculture, Agricultural Research Service. 25 p.

Lavin, Fred; Johnsen, T. N., Jr. 1977b. Species adapted for planting Arizona pinyon-juniper woodland. Journal of Range Management. 30(6): 410-415.

Plummer, A. Perry; Christensen, Donald R.; Monsen, Stephen B. 1968. Restoring big-game range in Utah. Publication 68-3. Salt Lake City, UT: Utah Division of Fish and Game. 183 p.

Ralphs, Michael H.; Busby, Frank E. (Fee). 1978. A project that made a second spring for Park Valley. Rangeman's Journal. 5(3): 86-88.

Ralphs, Michael H.; Busby, Frank E. 1979. Prescribed burning: vegetative change, forage production, cost, and returns on six demonstration burns in Utah. Journal of Range Management. 32(4): 267-270.

Reynolds, H. G.; Springfield, H. W. 1953. Reseeding southwestern rangelands with crested wheatgrass. Farmers' Bulletin 2056. Washington, DC: U.S. Department of Agriculture. 20 p.

Stevens, Richard. 1983. Species adapted for seeding mountain brush, big, black, and low sagebrush, and pinyon-juniper communities. In: Monsen, Stephen B.; Shaw, Nancy, compilers. Managing Intermountain rangelands—improvement of range and wildlife habitats: Proceedings; 1981 September 15-17; Twin Falls, ID; 1982 June 22-24; Elko, NV. Gen. Tech. Rep. INT-157. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 78-82.

West, Neil E.; Hassan, M. A. 1985. Recovery of sagebrush-grass vegetation following wildfire. Journal of Range Management. 38(2): 131-134.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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

Intermountain Research Station
324 25th Street
Ogden, UT 84401

United States
Department of
Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-385

October 1988

A Field Guide for Predicting Snow Damage to Ponderosa Pine Plantations

Walter F. Megahan
Robert Steele[1]

ABSTRACT

Describes a procedure for predicting potential damage to ponderosa pine plantings due to weight and movement of snowpack. Provides an example of the procedure for field use and discusses management implications of planting ponderosa pine in areas with high potential for snow damage. Current area of application covers the Weiser and Payette River drainages in central Idaho.

KEYWORDS: reforestation, silviculture, forest management, tree damage, snow pressure

INTRODUCTION

For more than five decades, ponderosa pine (*Pinus ponderosa* Laws.) has been the preferred species for reforesting burned and cut-over areas in many of the warmer and drier portions of the Northern Rockies. Because of its high timber value, ease of establishment, dependable growth rates, and lower susceptibility to insects and disease, this tree is usually preferred to other species. Although researchers have reported on susceptibility to snow damage of various conifers in the Western United States (Kangur 1973; Leaphart and others 1972; Schmidt and Schmidt 1979; Watt 1951, 1960; Williams 1966), we could find no reports of damage by snowpack to ponderosa pine in the Northern Rockies. Snow damage to ponderosa pine has been reported in California (Powers and Oliver 1970) and Arizona (Ffolliott and Thompson 1976; Schubert 1971).

Most damage studies have been concerned with wet snowfalls that overload tree crowns and cause bending and deformation. Our study deals with damage caused mainly by lateral snow movement and pressure against the stem, although some damage from crown overloading may have also occurred. Recent reconnaissance of ponderosa pine plantations in west-central Idaho revealed widespread snowpack damage to pine saplings under certain site conditions. Some damage to Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) was also noted but was less widespread. Type and degree of damage varied from bent (probably temporarily) terminal stems to permanent 90 degree bends in the main stem and to entire saplings pushed into permanent, critical departures from vertical (fig. 1). Other causes of deformed trees included rodents, soil creep, and rolling rocks or debris, but these were of minor importance compared to the effects of snow.

Once deformed, the pine's height growth is reduced (Rehfeldt 1987; Williams 1966), compression wood forms on the downhill side of the stem (Panshin and others 1964), and the tree becomes increasingly vulnerable to shrub competition. In some cases, severely deformed trees are killed by the brown-felt snow mold (*Neopeckia coulteri* [PK.] Sacc.) during years with prolonged snow cover. Thus snow damage may reduce timber yield, wood quality, and plantation survival.

A recent study involved the evaluation of 45 ponderosa pine plantations in the Douglas-fir/ninebark and the grand fir/mountain maple habitat types. Prior to logging, all of these sites appear to have supported naturally established ponderosa pine in varying amounts. These two habitat types represent some of the more productive timber sites in southwestern Idaho, and a common practice was to clearcut and plant ponderosa pine. The high potential for shrub competition usually required that contour stripping or pile-and-burn site preparation be used on these sites. Slopes too steep for these treatments were often broadcast burned.

Many of the pine plantations studied exhibited snow damage. Plantations were considered as damaged if more than 10 percent of the trees were obviously deformed by snow. Snow damage occurred to 65 percent (22) of the 34 grand fir/mountain maple sites sampled, but to only 9 percent (1) of the 11 Douglas-fir/ninebark sites. Actual percentage of damaged trees ranged from close to 10 percent to virtually 100 percent.

Analyses of snow-damaged versus undamaged pine plantations revealed that certain site features were related to snow damage. These findings led to development of a procedure for predicting snow damage potential from site features easily obtained by forest managers (Megahan and Steele 1987). The purpose of this paper is to adapt the snow damage assessment procedure for field use.

The present area of application includes the Weiser and the Payette River drainages in west-central Idaho (fig. 2).

---

[1] Principal research hydrologist and research forester, respectively, located at Intermountain Station's Forestry Sciences Laboratory, Boise, ID.

Figure 1a, b—Snow-damaged ponderosa pine.

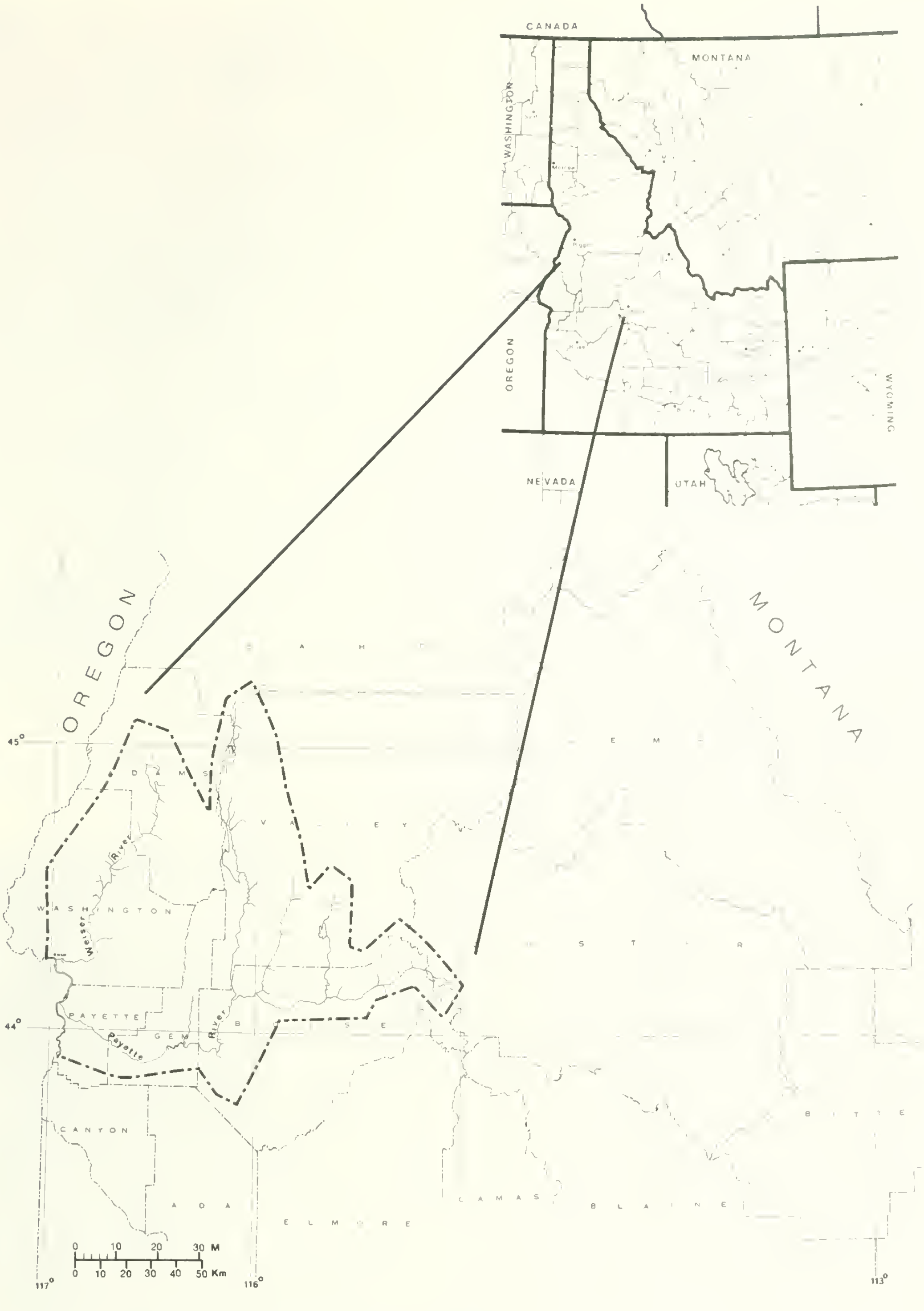


Figure 2—Area covered by the field guide to predicting snow damage.

Annual precipitation, mostly snowfall, ranges from 25 inches at the lowest elevation to 60 inches at the highest elevation. Topography is typical of that found in the Northern Rocky Mountains, with steep, dissected slopes ranging in gradient from 10 to 100 percent. Geology includes the intrusive, acid, igneous rocks of the Idaho batholith as well as the extrusive, more basic rocks of the Snake River basalts. Granitic soils are coarse textured, shallow, and poorly developed, and tend to be slightly acidic. In contrast, basaltic soils are finer textured, deeper, better developed, and more basic than the granitic soils.

PROCEDURE FOR PREDICTING SNOW DAMAGE

Snow that accumulates on the ground undergoes a change in its crystalline structure that causes a plastic deformation of the snowpack and exerts pressure on young trees. Three types of snowpack movement can occur,

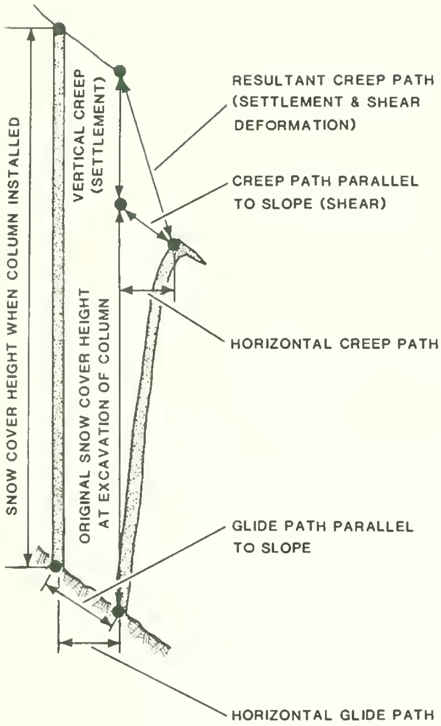


Figure 3—Example of snow glide and creep (after Frutiger and Kuster 1967).

namely vertical settlement at all sites plus creep and glide on steeper slopes. Snow creep refers to differential motion throughout the pack with more movement in upper layers than in lower layers. Glide involves the slow downslope movement of the entire snowpack along the soil-snow interface (fig. 3). Glide tends to be greater on south aspects, is directly proportional to snow depth, and is inversely proportional to slope roughness. Frutiger and Kuster (1967) documented glide movement of up to 3 feet or more on study slopes in Switzerland. Creep varies directly with snow depth, snow density, and slope gradient. Martinelli (1960) measured snow creep averaging more than 7 inches per 70 inches of snow depth on snow fields in Colorado. Frutiger and Martinelli (1966) adapted the snow pressure concept, originally presented by Haefeli (1951), to quantify the static forces caused by creep and glide in a snowpack. We used a multiple, discriminant analysis to adapt the snow pressure approach to predict snow damage hazards on ponderosa pine plantations (Megahan and Steele 1987).

In order to calculate snow pressure for each plantation, the following site data are needed:

1. Elevation in feet
2. Slope gradient in percent
3. Slope azimuth in degrees
4. Roughness (a rating based on site characteristics).

Measurement precision for the various factors should be: elevation – 100 feet; slope gradient – 5 percent; slope azimuth – 10 degrees; roughness – 0.1.

Table 1—Roughness as defined by surface features (derived from Frutiger 1962)

Surface feature	Roughness
Class I	
Big boulders (d[1] >30 cm, 12 in)	
Terrain with more or less big outcroppings of rock	1.2
Class II	
Surface covered with shrubs at least 1 m (39.4 in) tall	
Well-expressed mounds covered by grass and low shrubs; mounds must be at least 50 cm (20 in) high	
Well-pronounced livestock or game trails	
Boulders (d[1] about 10-30 cm, 4-12 in)	1.6
Class III	
Short grass (such as pinegrass) with shrubs less than 1 m (39.4 in) in height	
Small boulders (d[1] <10 cm, 4 in) intermingled with grass and shrubs	
Only a few mounds up to 50 cm (20 in) tall covered by grass and shrubs	
Grass with indistinct livestock or game trails	2.0
Class IV	
Long-bladed grass (such as bromes)	
Smooth rock plates with stratification planes parallel to slope	
Smooth scree or scree-soil mixtures	
Swampy depressions	2.6

[1] d is diameter of the blocks that determine roughness of the surface.

The calculation assumes uniform site conditions within the plantation. If there are large variations in any of the site factors, the plantation should be divided into subunits and calculations made accordingly. Roughness is determined with the use of table 1 and the photographs illustrating various levels of roughness (figs. 4-7). Interpolations can be made between roughness levels if necessary.

Snow pressure (P) is calculated as the product of three variables as follows:

$$P = D * C * G$$

where

P = snow pressure in pounds per foot of tree diameter
D = depth factor in pounds per foot of tree diameter
C = creep factor
G = glide factor.

The depth factor (D) is obtained from figure 8. Enter figure 8 at the appropriate elevation in feet and project a vertical line to the curve. At the intersection of the curve, project a horizontal line to the left to read the depth factor (see example on fig. 8). The creep factor (C) is obtained from figure 9 in a similar manner as for the depth factor on figure 8 except that the figure consists of a family of curves representing various slope gradients. In this case, the appropriate slope gradient for the site is used as the point of intersection. Interpolate between the curves if

Figure 4—An example of class I roughness (1.2) due to the many downed logs and tall stumps; boulders and rock outcroppings can create the same effect. This site occurs at 7,700 feet in elevation with a 20-degree azimuth and a 55 percent slope. These site conditions can produce snow pressures of 1,210 pounds/foot.

Figure 5—An example of class II roughness (1.6) due to the nearly complete cover of tall shrubs. This site occurs at 5,930 feet in elevation with a 240-degree azimuth and a 38 percent slope. These site conditions can produce snow pressures of about 365 pounds/foot and result in damaged pine plantations as shown.

Figure 6—An example of class III roughness (2.0) due to the scattered low shrubs and cover of short grass, sedges, and forbs. This site occurs at 5,500 feet in elevation with a 40-degree azimuth and 34 percent slope. These conditions can produce snow pressures of about 205 pounds/foot, resulting in some snow damage to pine saplings.

Figure 7—An example of class IV roughness (2.6) due to the smooth surface and extensive cover of tall grass. This site occurs at 5,050 feet in elevation with a 260-degree azimuth and a 36 percent slope. In spite of the smooth surface, the combination of these conditions can only produce snow pressures of about 160 pounds/foot, resulting in pine saplings with virtually no snow damage.

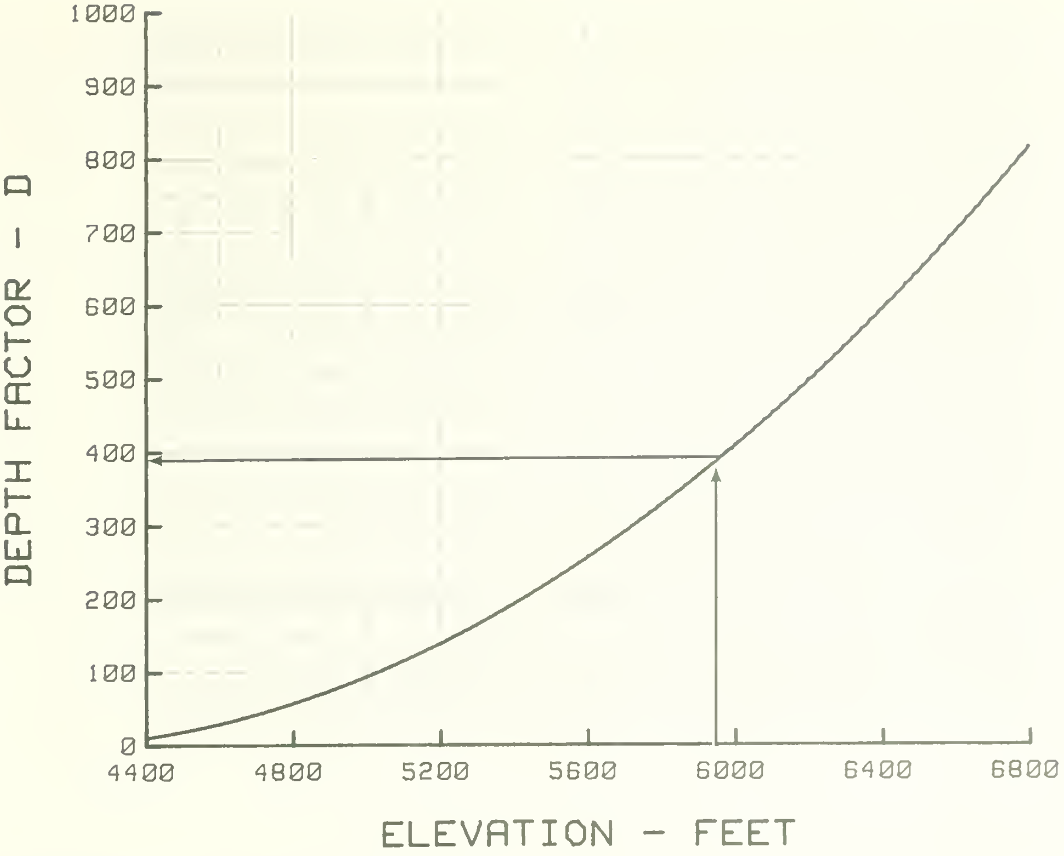


Figure 8—Depth factor as a function of elevation.

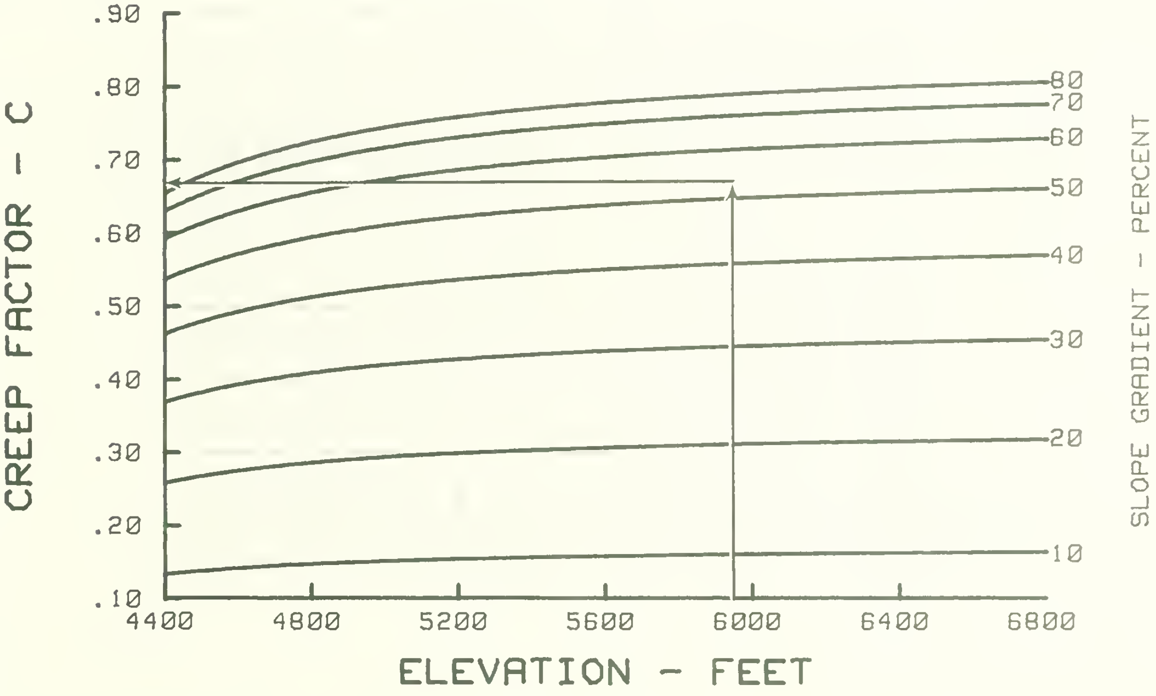


Figure 9—Creep factor as a function of elevation and slope gradient.

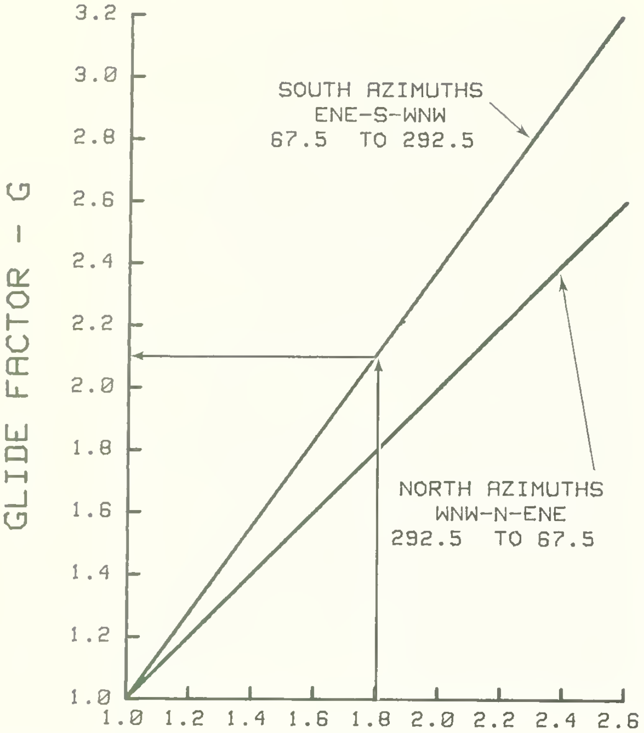


Figure 10—Glide factor as a function of roughness and azimuth.

necessary for intermediate slope gradients (see example). The final component, glide factor (*G*), is obtained from figure 10 from the slope roughness and the azimuth for the site. Enter the figure with slope roughness, project a vertical line to the correct azimuth class, then read horizontally to the left to obtain the glide factor (see example).

The product of the depth, creep, and glide factors is the snow pressure for the plantation. A hypothetical example to illustrate the calculation procedure is as follows:

Slope gradient = 53 percent
Slope azimuth = 170 degrees
Elevation = 5,950 feet
Roughness = 1.8

Entering figure 8 at an elevation of 5,950 feet, find a depth factor of 390. Enter figure 9 with an elevation of 5,950 feet and obtain a creep factor of 0.67 for the slope gradient of 53 percent. For the roughness of 1.8, obtain a glide factor of 2.10 from figure 10, using the south azimuth curve (based on the plantation azimuth of 170 degrees). Note that the glide factor is greater on south aspects than on north aspects. The snow pressure for the site is the product of the depth, creep, and glide factors of 390, 0.67, and 2.10, respectively, and equals 549 pounds per foot.

USE OF THE SNOW DAMAGE PREDICTION PROCEDURE

Megahan and Steele (1987) show that plantations are subject to damage if snow pressures are equal to or greater than 188 pounds per foot of tree diameter. The overall prediction success for this procedure averages 80 percent at a level of confidence of 95 percent (74 percent correct for plantations predicted as damaged that are actually damaged and 91 percent correct for plantations predicted as undamaged that are actually undamaged). The hypothetical plantation site given in the example above had a predicted snow pressure of 549 pounds per foot and is a candidate for serious snow damage!

The snow damage prediction procedure presented here was developed for the study area shown in figure 2. An important component of the procedure is a relationship between elevation and the 20-year average (1961-80) annual snow depth at the time of annual maximum snow water content at the site. Such a relationship was developed from 24 snow courses operated within the study area as a part of the USDA Cooperative Snow Survey network. The resulting elevation-snow depth relationship may not apply outside the Weiser and Payette River drainages (fig. 1). Thus, the prediction results obtained from figures 8, 9, and 10 should not be used for areas outside these areas without validation. Megahan and Steele (1987) discuss the approach for development of the snow damage prediction procedure for other locations.

At current development, the prediction procedure allows us to define the threshold for damage. Common sense and our observations suggest that damage is directly proportional to the amount that predicted snow pressures exceed the threshold. Additional research is needed to define the nature of this relationship as well as recovery capabilities of damaged trees in relation to seed sources. In the meantime, the snow pressure prediction procedure provides a means to "red flag" probable damage potential.

MANAGEMENT IMPLICATIONS

Where ponderosa pine has been chosen for reforestation, selecting seedlings from the proper genetic seed source is critical. Seedlings from improper seed sources may be less likely to recover from snow bending. But it should not be assumed that pine seed from appropriate elevations will result in successful plantations on sites where high snow pressure is predicted and ponderosa pine was never a predominant species. In high-snow-hazard areas, forest managers should consider silvicultural alternatives other than clearcutting and planting ponderosa pine. If there are no alternatives, then special care should be taken to protect the planted ponderosa pines. The site should be carefully inspected, including during the period of maximum snow accumulation. This will enable silviculturalists to identify and avoid planting of localized deep snow sites such as the lee side of adjacent uncut stands, the lee side of ridges, and the toe slope of cut banks or road beds. Additional protection can be provided by planting trees downhill from local obstructions that reduce downslope creep and glide, such as stumps, rocks, and logs. Intense broadcast burning should be avoided on these sites because this treatment removes logging debris and stimulates shrub development. The shrubs can then outcompete the planted pines more easily because snow damage has reduced growth rates of the young trees and the trees, in turn, spend more years within the snow damage window. Obviously, the best time to make these assessments is during preparation of the initial site prescription so that necessary mitigating measures can be included.

REFERENCES

Ffolliott, P. F.; Thompson, J. R. 1976. Snow damage in Arizona ponderosa pine stands. Res. Note RM-332. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.

Frutiger, H. 1962. Avalanche control in the starting zone. [Translation of Swiss guidelines]. Paper 71. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 60 p.

Frutiger, H.; Kuster, J. 1967. Veber das gleiten und kriechen der schneedecke in lawinenverbauugen. On slide and creep of the snow cover among avalanche defenses. Schweizerischen Zeitschift fuer Forstwesen. 10: 633-643. [Chapelle, E. Translation No. 9. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Wasatch National Forest, Alta Avalanche Study Center.]

Frutiger, H.; Martinelli, M. Jr. 1966. A manual for planning structural control of avalanches. Res. Pap. RM-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 68 p.

Haefeli, R. 1951. Nevere entwicklungstendenzen und probleme des lawinenverbaus in autruchgebiet. Mitteilungen des Eidg Institutes fur Schnee-und Lawinen forschung. 9: 28-56.

Kangur, R. 1973. Snow damage to young western hemlock and Douglas-fir. Res. Pap. 21. Corvallis, OR: Oregon State University, School of Forestry. 11 p.

Leaphart, C. D.; Hungerford, R. D.; Johnson, H. E. 1972. Stem deformities in young trees caused by snowpack and its movement. Res. Note INT-158. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 10 p.

Martinelli, M., Jr. 1960. Creep and settlement in an alpine snowpack. Res. Note 43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Megahan, W. F.; Steele, R. 1987. An approach for predicting snow damage to ponderosa pine plantations. Forest Science. 33(2): 485-503.

Panshin, A. J.; DeZeeuw, C.; Brown, H. P. 1964. Textbook of wood technology. Vol. 1. New York: McGraw-Hill. 643 p.

Powers, R. F.; Oliver, W. W. 1970. Snow breakage in a pole-sized ponderosa pine plantation...more damage at high stand-densities. Res. Note PSW-218. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 3 p.

Rehfeldt, G. E. 1987. Components of adaptive variation in *Pinus contorta* from the Inland Northwest. Res. Pap. INT-375. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Schmidt, W. C.; Schmidt, J. A. 1979. Recovery of snowbent young western larch. Gen. Tech. Rep. INT-54. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

Schubert, G. H. 1971. Growth response of over-aged ponderosa pine stands related to stand density level. Journal of Forestry. 69: 857-860.

Watt, R. F. 1951. Snow damage in a pole stand of western white pine. Res. Note 92. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Rocky Mountain Forest and Range Experiment Station. 4 p.

Watt, R. F. 1960. Second-growth western white pine stands. Tech. Bull. 1226. Washington, DC: U.S. Department of Agriculture, Forest Service. 60 p.

Williams, E. B., Jr. 1966. Snow damage to coniferous seedlings and saplings. Res. Note PNW-49. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 10 p.

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

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