Interactions of Fire and Dwarf Mistletoe on Mortality of Southwestern Ponderosa Pine[1]

Michael G. Harrington and Frank G. Hawksworth[2]

Abstract.—A ponderosa pine stand infected with dwarf mistletoe was prescribed burned in Grand Canyon National Park. The degree of dwarf mistletoe infection positively influenced the degree of crown scorch. Amount of scorch was the dominant factor in first-year mortality. However, in the medium scorch classes, tree mortality increased as infection increased. Results suggest that dwarf mistletoe can be managed with prescribed fire.

Little is known about the effect of fire injury on pines infected with dwarf mistletoe (*Arceuthobium* ssp.) (Alexander and Hawksworth 1975). A prescribed burn on permanent plots in ponderosa pine (*Pinus ponderosa* subsp. *scopulorum* [Engelm.] E. Murray) on the South Rim of Grand Canyon National Park, Arizona, enabled us to compare fire-kill in trees with various intensities of dwarf mistletoe infection (*Arceuthobium vaginatum* subsp. *cryptopodum* [Engelm.] Hawksw. and Wiens).

Although fire has long been considered the primary natural control agent of dwarf mistletoe (Hawksworth 1961, Roth 1953), little quantitative information on the subject is available, particularly for ponderosa pine. Koonce and Roth (1980, 1985) studied the effects of prescribed fire on survival of ponderosa pines affected by a similar dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) in Oregon. They concluded that the dwarf mistletoe could be partially sanitized from thinned and unthinned ponderosa pine stands by prescribed understory burning. Their studies were conducted in immature, even-aged stands and not in uneven-aged stands such as we describe here for the Grand Canyon study. The objective of this study was to determine the effect of various combinations of crown scorch and dwarf mistletoe infection on first-year mortality of ponderosa pine.

[1]Poster paper presented at the conference, Effects of Fire in Management of Southwestern Natural Resources (Tucson, AZ, November 14-17, 1988).

[2]Harrington is a Research Forester, Intermountain Fire Sciences Laboratory, Intermountain Research Station, Missoula, MT 59807. Hawksworth is a Research Plant Pathologist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO 80526.

Methods

The Grand Canyon plots were established in 1950 as part of a dwarf mistletoe control project (Lightle and Hawksworth 1973, Maffei 1984). A portion of the study area was treated for dwarf mistletoe by pruning or cutting infected trees. The rest of the study area was left untreated as a control. This paper presents results from the untreated study area only. From 1950 to 1982, stand characteristics and dwarf mistletoe infection had changed considerably. Stand density for trees greater than 3 inches diameter breast height (d.b.h.) decreased from 29 trees per acre to 19 trees per acre, while average d.b.h. increased from 14.5 to 15.6 inches. The percentage of infected trees has not changed from about 80%, but the average dwarf mistletoe rating increased from 2.8 to 3.7 on the 6-class scale. In this 6-class system, the tree crown is divided horizontally into thirds. Each third is given a rating of 0 (no mistletoe), 1 (light mistletoe), or 2 (heavy mistletoe). The three ratings are totaled to give a tree rating that may range from 0 (no mistletoe) to 6 (entire tree heavily infected) (Hawksworth 1977).

Fire Treatment

The dwarf mistletoe study area was prescribed burned by the National Park Service as part of a 600-acre fuel and stand density reduction burn. The burning began August 9, 1985, and continued until heavy rains extinguished the flames on August 24 (Ray 1985). After fire lines were burned out, fires were allowed to spread at will over much of the area. Fire intensities were generally low to moderate throughout the 15 days of burning, with the exception of some crowning in a 1-acre sapling thicket as heavy fuels burned with gusty winds. Most of the crown scorching resulted from burning of heavy surface fuels. Over the 600 acres, the fire reduced the average duff depth of 1 inch by about 40% and the total down woody fuel loading of 5.6 tons per acre by 33%. Ponderosa pine saplings less than 3 inches d.b.h. were reduced by 52% from a preburn average of 320 trees per acre (Ray 1985). Weather and fuel moisture information from the fire was not available.

Damage Evaluation

This prescribed burn provided an opportunity to study the effects of fire damage on the 191 sample trees in the untreated plot that had been given dwarf mistletoe ratings (DMR) in 1982. Each tree was given one of five crown scorch ratings based on percentage of crown length that was scorched. Key scorch values and approximate ranges are as follows: 0% (0-12%), 25% (13-37%), 50% (38-62%), 75% (63-87%), and 100% (88-100%). Each tree was also put into one of five bole char categories: 0 = unburned around tree, 1 = duff burned but no bark char, 2 = light bole char, 3 = moderate bole char, and 4 = severe bole char with much bark consumption.

On November 19, 1986, all trees were surveyed for vitality, In most cases, trees were either classified as live with good vigor or clearly dead. A small percentage was initially classified as live with little chance of survival based on yellowing crowns. In the analyses, these trees were put into the dead category.

Analysis

Logistic regression models have been used in other tree damage studies to predict the probability of survival or mortality given specific tree and damage characteristics (Bevins 1980, Peterson and Arbaugh 1986, Ryan et al. 1988). Details of logistic regression theory and development can be found in Monserud (1976). The independent variables tested for value in predicting probability of survival were tree d.b.h., crown scorch class (CS), dwarf mistletoe rating (DMR), and bole char (BC). The first three are continuous variables of a quantitative nature with equal class widths while bole char is a classification or qualitative variable. The CATMOD proceedure of the SAS[3] statistical package was used for model development.

[3]The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

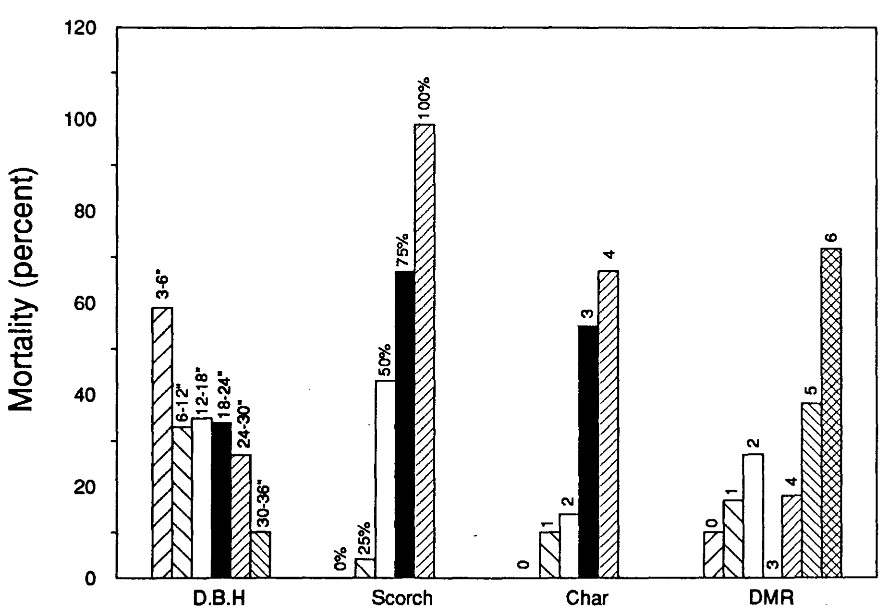

Figure 1.—Effects of d.b.h., scorch, bole char, and DMR on tree mortality. Descriptors are defined in the text.

Results

The fire damage resulted in first-year mortality of 34% of the 191 sample trees. Generally, mortality increased with decreasing tree size and with increasing crown scorch, bole char, and dwarf mistletoe infection (fig. 1). With a given fire intensity, small trees normally sustain greater damage because their crowns are closer to the heat source and their bark is thinner (Lynch 1959, Harrington 1987). In this study, 28% of trees between 3 and 12 inches d.b.h. had greater than 50% of their crowns scorched, compared to 19% of the trees greater than 24 inches d.b.h. Logically, the greater the fire damage, the greater the mortality, whether damage was crown scorch or bole char (fig. 1). There was 100% mortality for trees with greater than 87% crown scorch, whereas the most severe bole char resulted in about 67% mortality. Finally, a general trend of increasing mortality with increasing degree of mistletoe infection is apparent, with some fluctuations.

The influence dwarf mistletoe infection had on pine mortality can be inferred by comparing average pre-fire DMR of surviving and dead trees. The average DMR for trees not surviving the fire was 4.8 compared to 2.9 for surviving trees. For the entire stand, the average DMR was reduced from 3.7 to 2.9 as a result of the fire. Even though this reduction occurred in all size classes, it was more pronounced in the smallest trees. Average DMR decreased from 2.4 to 1.2 for trees between 3 and 12 inches d.b.h., from 4.2 to 3.6 for trees 12 to 24 inches d.b.h., and from 4.2 to 4.0 for trees greater than 24 inches d.b.h.

Figure 2 shows tree frequencies in various scorch class and DMR class combinations. Two trends are apparent. The percentage of trees with little or no scorch decreased as DMR increased, compared to an increase in the percent of trees with moderate to severe scorch as DMR increased. Koonce and Roth (1985) showed that mistletoe-infected trees do not self-prune as readily as healthy trees. In their study, average height to crown bottom was 21% of infected tree height, compared to a crown bottom height of 38% for healthy trees. This implies that for a given scorch height, a greater portion of an infected tree's crown length will be scorched.

Another indicator of the relationship of scorch to DMR is shown in figure 3. The average amount of crown scorch generally increased as amount of dwarf mistletoe increased. An exception is DMR class 3, which had a sample size of only seven trees.

Mortality increased with increasing scorch, bole char, and DMR, and decreasing tree size (fig. 1). A logistic regression was developed to estimate the probability of survival using these four independent variables. The first attempt showed that bole char was not significant for predicting survival, therefore was not used. The best regression for predicting probability of tree survival was

$$Ps = 1/(1 + e^{(4.91 + 0.10\,d.b.h. - 0.10\,CS - 0.29\,DMR)}) \quad (1)$$

where Ps = probability of survival, e = base of the natural log, d.b.h. = tree diameter (inches), CS = crown scorch (percent), and DMR = dwarf mistletoe rating. The independent variables had moderate to high significance for prediction of survival; p(d.b.h.) = 0.03, p(CS) < 0.01, and p(DMR) = 0.07. Using the 50% probability level to delineate live and dead trees, the model correctly predicted vitality for about 92% of the trees. Eleven trees (5.8%) were dead when predicted to be alive, and five (2.6%) were alive when predicted to be dead.

Using the probability regression, figure 4 was generated to show the influence of scorch and dwarf mistletoe classes on probability of tree survival. The degree of crown scorch obviously has the greatest influence on survival as most trees are expected to survive within the range of the two least scorch classes, and most trees are expected to die in the greatest scorch class. DMR does influence survival within the range of the 50% and 75% scorch classes (total range is 38% to 87%). Severity of mistletoe infection is important with about 50% crown scorch of small trees, with from 50% to 75% crown scorch of medium-sized trees, and with about 75% crown scorch of large trees (fig. 4).

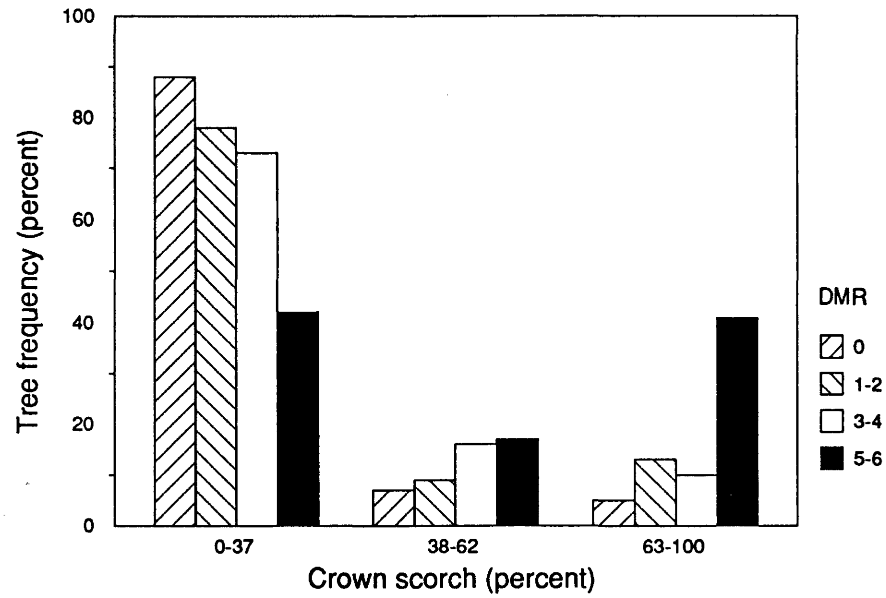

Figure 2.—Tree frequency in crown scorch classes by DMR groups.

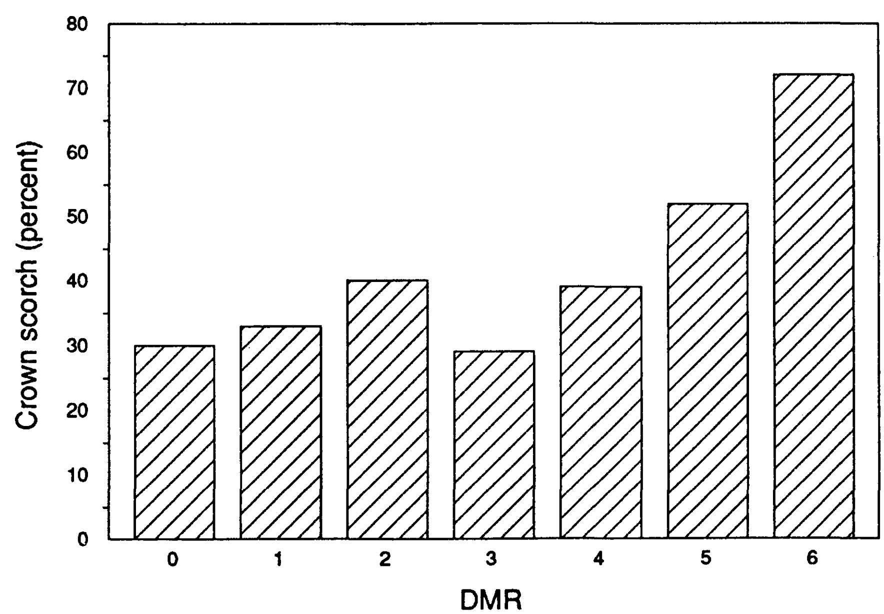

Figure 3.—Average crown scorch for each DMR class.

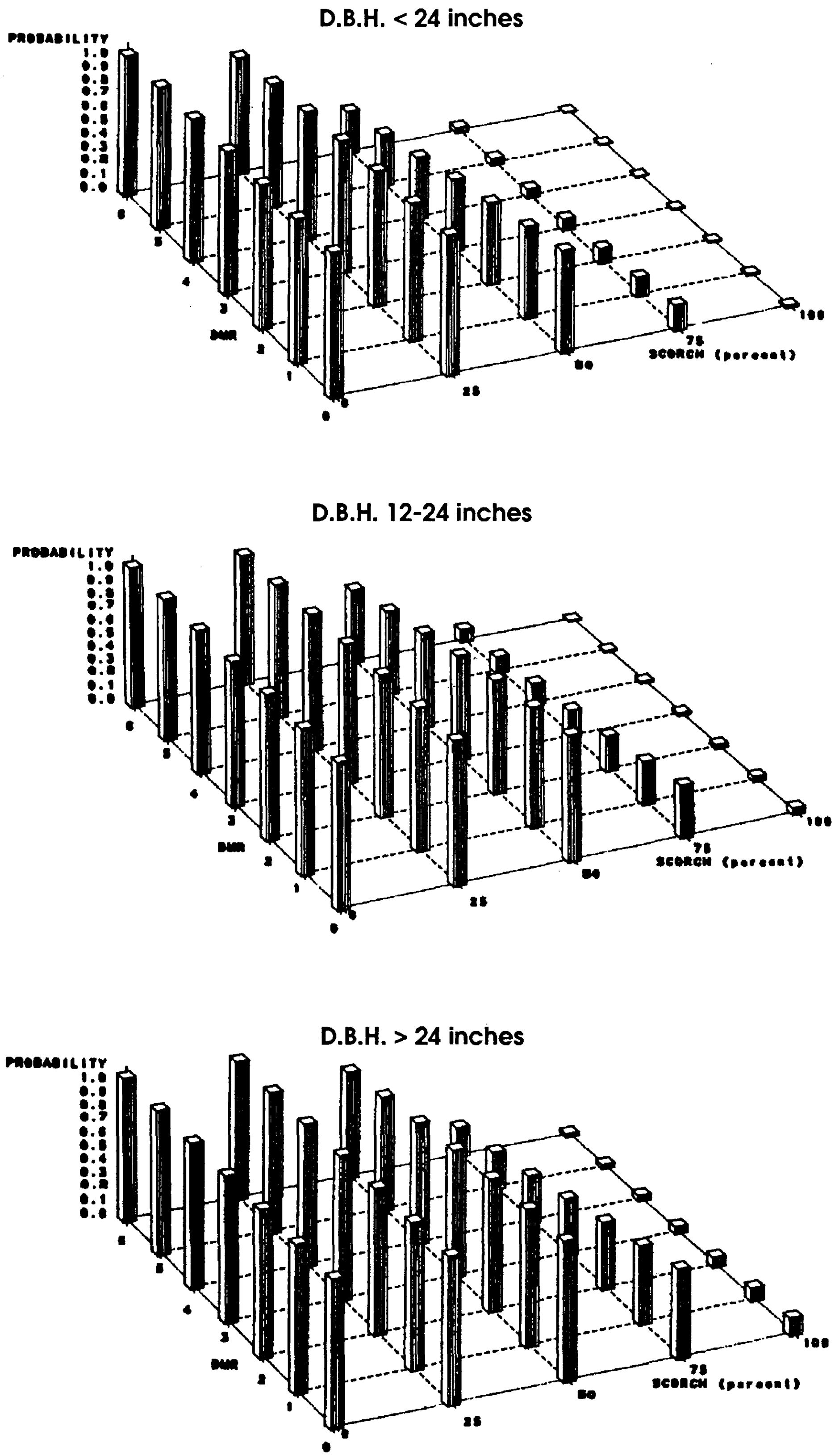

Figure 4.—Survival probability for ponderosa pine in five crown scorch classes and six DMR classes.

Figure 5 demonstrates the differences in survival probability between trees with two levels of dwarf mistletoe infection and within two key scorch classes. For an 8-inch tree with about 50% scorch, lack of mistletoe infection would lead to a 71% chance of survival, which drops to 30% for severely infected trees. Similarly, for a 30-inch tree with about 75% crown scorch, the probability of survival drops from 65% with no infection to 25% with severe infection. In other words, almost two-thirds of the large trees in good health would be expected to survive a fire damaging three-fourths of their crowns, while only about one-fourth of the trees with severe mistletoe infection could survive that same level of crown scorch.

Discussion

Dwarf mistletoe-infected trees are apparently influenced by fire in two ways. First, a larger portion of an infected tree's crown will likely be scorched with a fire of given intensity than a healthy tree's crown because of a tendency of the former to have flammable witches brooms and low crowns. Second, with equal amounts of crown scorch within the 38% to 87% range, heavily infected trees have less than half the probability of survival that uninfected trees have. This might occur simply because infected trees are less healthy, making any damage more life-threatening. In addition, if infected trees have a greater crown length than uninfected trees, similar percentage of scorching would mean a greater absolute crown volume loss in infected trees, leaving only the relatively thin, unhealthy crown tops to maintain tree vitality.

In comparison, a study in southwestern Colorado also documented crown scorch and mortality of ponderosa pine from spring, summer, and fall prescribed burns (Harrington 1987). First year mortality following a mid-August burn in Colorado was 21% compared to 35% in our study. Several differences between study sites should be pointed out. Average diameter for trees larger than 3 inches d.b.h. was greater at the Grand Canyon site (15.6 vs. 9.5 inches). Greater general fire damage occurred at the Colorado site where 26% of the trees had 33% to 90% crown scorch compared to only 14% of the trees at the Grand Canyon. About equal percentages were scorched more than 90%. The pronounced difference probably resulting in the greater mortality at Grand Canyon, even with larger trees and less fire damage, was the widespread dwarf mistletoe infestation, which was not a factor at the Colorado site.

Key points in the discussion of dwarf mistletoe management with fire are as follows:

1. How much scorch pruning (entire branch kill) would be required for a tree or stand with a specific DMR to minimize the dwarf mistletoe infection?

2. Given the amount of scorching required, DMR, and tree size, what is the probability of tree survival?

3. If low survival is indicated, should the tree be killed and/or removed, or scorched to a lower level to improve immediate survivability?

Because dwarf mistletoe rating denotes the amount and severity of infection, it also designates that portion of the crown that should be scorch-killed for sanitation. For example, a DMR = 1 or 2 means that the lower third of the crown requires treatment; and a DMR = 5 or 6 means that the entire crown is infected, so for complete mistletoe elimination the tree would have to be killed.

An important point to consider in scorch pruning is that generally a lesser number of branches that have scorched foliage are actually killed because needles are killed easier than buds (Wagener 1961). As Ryan (1982) pointed out, species with large buds such as ponderosa pine will have bud and branch survival from a few to many feet below needle scorch depending on season of damage. Therefore, if a given percentage of scorch pruning is required, a larger percentage of the crown length needs to be scorched for the specified amount of crown to be actually killed. Therefore, to eliminate mistletoe from a tree in DMR = 1 or 2, 50% average crown scorch would be recommended. Then, knowing the amount of crown scorch needed to reduce or eliminate a specific degree of infection, an estimation of the survival probability can be made using equation [1] or figure 5.

If the probability of survival is indicated to be low, then one of two choices needs to be made based on the management objectives and silvicultural opportunities for the site. First, the tree could be killed or harvested because of poor vigor and possiblity of mistletoe dispersion. Second, the scorch level could be reduced, which would lead to an increase in probability of survival but leave some mistletoe within the residual crown.

Lightle and Hawksworth (1973) reported that there is utility in pruning severely infected lower branches from moderately to heavily infected trees. They demonstrated that trees with DMR = 4 and 5 responded to partial pruning (broom pruning) with prolonged life, vigor recovery, and growth improvement even though dwarf mistletoe was not eliminated.

A discussion of techniques for producing various degrees of scorch pruning are beyond the scope of this paper. Scorch height depends upon fireline intensity, air temperature, and windspeed (Van Wagner 1973). It can be estimated much easier using flame lengths rather than fireline intensity (Albini 1976), and can be crudely predicted using fire behavior models (Susott and Burgan 1986). In all situations where scorch-pruning is attempted, burners must be experienced in the application of prescribed fire and have good fire effects knowl-

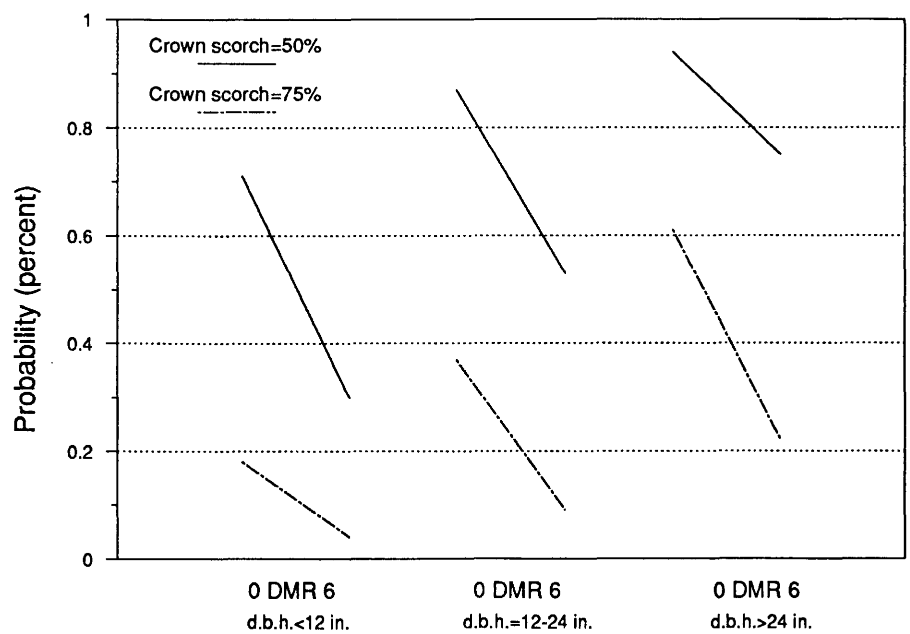

Figure 5.—Survival probability for ponderosa pine in three d.b.h. classes, two crown scorch classes, and two DMR classes.

edge to utilize proper ignition techniques (Kilgore and Curtis 1987).

The preceding discussion dealing with the potential use of fire for scorch-pruning dwarf mistletoe infected branches is based primarily on the results of this study alone. Results would likely be different if burning took place in the early spring or late fall. Therefore, the details are preliminary at best and require further investigation before wide use is recommended. However, these results show enough promise for practical application in an important area of forest management that they should be used at least as a starting point for developing guidelines for dwarf mistletoe management by prescribed fire.

Management Implications

Because presettlement fires played a major role in dwarf mistletoe abundance and distribution by eliminating severely infected dense stands (Alexander and Hawksworth 1975) and by pruning moderately infected open stands (Roth 1974), prescribed fire should not be overlooked as a possible management tool for mistletoe control. The most manageable opportunity for mistletoe control appears to be in heavily infected stands where patch clearcutting would be followed by intense broadcast burning. However, at least partial sanitation also seems possible in existing stands with light to moderate infection using specifically prescribed understory burning.

It is apparent that light crown scorching (less than 37%) will generally have little effect on tree mortality, and severe crown scorching (greater than 87%) will most often lead to death, regardless of DMR. Degree of dwarf mistletoe infection does influence survivability within the 50% to 75% crown scorch classes. This information can be used in various ways by timber, fire, range, and wildlife specialists because prescribed fires generally have multiple purposes including vegetation manipulation, hazard reduction, and site preparation.

One particular use would be in a ponderosa pine stand occupied by trees with varying severities of dwarf mistletoe. If harvesting the moderately to heavily infected trees is not feasible, a prescribed burn could be planned to produce a specified range of crown scorch such that heavily infected trees would have a low survival probability compared to uninfected trees. As an example using equation [1] or figure 5, if a group of trees averaging 8 inches d.b.h. were scorched to about the 50% level, trees with DMR ≤ 1 would have about a 70% chance of survival, whereas those with DMR ≥ 5 would have about a 30% chance of survival. In this study area, the disproportionate death of heavily infected trees led to an average decrease in stand DMR from 3.7 to 2.9. By exerting more control over the fire behavior under trees with various degrees of infection, the stand DMR could have been reduced further.

Another example uses this information as a guide for attempted mistletoe reduction in trees to be retained. Dwarf mistletoe in lightly infected trees (DMR = 1-3) could be reduced with about 50% crown scorch, and the chance of survival would be quite good for all size classes, 52% to 97% (fig. 5). However, if DMR = 4 to 5, then an effective amount of scorch pruning, crown scorch $\geq 75\%$, would result in low survival, 5% to 40%, depending on tree size and DMR. For example, an 18-inch tree with DMR = 4 would require 75% crown scorch for mistletoe control, but this would result in a 15% probability of survival. If tree survival is important because logging is not possible, cover is needed, a seed source is desired, etc., then the crown scorch could be reduced to 50%, raising the probability of survival to almost 70%, and in many cases resulting in vigor recovery.

The management of dwarf mistletoe infected stands is complex. Clearcuts and stand-eliminating prescribed fires that are often used for mistletoe control are frequently looked upon unfavorably by many influential groups. Another option, then, for mistletoe management is presented here, in preliminary form, for further testing. Applying prescribed fire to attain specific levels of crown scorch is difficult, requiring much skill and a working knowledge of analytical tools. Results will never be completely definitive because of the natural variability of forest fuels, tree responses, and fire behavior. However, with further verification of the results presented here and more knowledge gained on the effects of heat and smoke on dwarf mistletoe, management guidelines could be developed for prescribed fire use in mistletoe control.

Literature Cited

Albini, Frank A. 1976. 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. 92 p.

Alexander, Martin E.; Hawksworth, Frank G. 1975. Wildland fires and dwarf mistletoes: a literature review of ecology and prescribed burning. Gen. Tech. Rep. RM-14. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Bevins, Collin D. 1980. Estimating survival and salvage potential of fire-scared Douglas-fir. Res. Note INT-287. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experment Station. 8 p.

Harrington, Michael G. 1987. Ponderosa pine mortality from spring, summer, and fall crown scorching. Western Journal of Applied Forestry 2(1): 14-16.

Hawksworth, Frank G. 1961. Dwarfmistletoe of ponderosa pine in the Southwest. Tech. Bull. 1246. Washington, DC: U.S. Department of Agriculture, Forest Service. 112 p.

Hawksworth, Frank 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.

Kilgore, Bruce M.; Curtis, George A. 1987. Guide to understory burning in ponderosa pine-larch-fir forests in the Intermountain West. Gen. Tech. Rep. INT-233. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 39 p.

Koonce, Andrea L.; Roth, Lewis F. 1980. The effects of prescribed burning on dwarf mistletoe in ponderosa pine. In: Proceedings of the Sixth Conference on Fire and Forest Meteorology. 1980 April; Seattle, WA. Society of American Foresters, Washington, DC. p. 197-203.

Koonce, Andrea L.; Roth, Lewis, F. 1985. The effects of dwarf mistletoe on fuel in precommercial ponderosa pine stands. In: Proceedings of the Eighth Conference on Fire and Forest Meteorology. 1985 April-May; Detroit, MI. Society of American Foresters, Washington, DC. p. 66-72.

Lightle, Paul C.; Hawksworth, Frank G. 1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. Res. Paper RM-106. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Lynch, Donald W. 1959. Effects of a wildfire on mortality and growth of young ponderosa pine. Res. Note INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Maffei, H. 1984. Control of dwarf mistletoe at the Grand Canyon: results after a third of a century. In: Proceedings of the Thirty-second Western International Forest Disease Work Conference. 1984 September; Taos, NM. p. 59-60.

Monserud, Robert A. 1976. Simulation of forest tree mortality. Forest Science 22: 438-444.

Peterson, David L.; Arbaugh, Michael J. 1986. Postfire survival in Douglas-fir and lodgepole pine: comparing the effects of crown and bole damage. Canadian Journal of Forest Research 16: 1175-1179.

Ray, John. 1985. National Park Service resource management report for the Grandview prescribed burn. U.S. Department of Interior, Grand Canyon National Park, AZ. Unpublished report, 8 p.

Roth, Lewis F. 1953. Pine dwarf mistletoe on the Pringle Falls Experimental Forest. Res. Note 91. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 3 p.

Roth, Lewis F. 1974. Juvenile susceptibility of ponderosa pine to dwarf mistletoe. Phytopathology 64: 689-692.

Ryan, Kevin C. 1982. Evaluating potential tree mortality from prescribed burning. In: Baumgartner, David, M., compiler. Site preparation and fuels management on steep terrain: Proceedings of a symposium; 1982 February; Spokane, WA. Washington State University, Pullman. p. 167-179.

Ryan, Kevin C.; Peterson, David L.; Reinhardt, Elizabeth D. 1988. Modeling long-term fire-caused mortality of Douglas-fir. Forest Science 34:190-199.

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 Forest and Range Experiment Station. 80 p.

Van Wagner, Charles E. 1973. Height of crown scorch in forest fires. Canadian Journal of Forest Research 3: 373-378.

Wagener, Willis W. 1961. Guidelines for estimating the survival of fire-damaged trees in California. Misc. Pap. 60. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 p.