Survival and Sanitation of Dwarf Mistletoe-Infected Ponderosa Pine following Prescribed Underburning

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ABSTRACT

We present results on survival of ponderosa pine and reduction in dwarf mistletoe (*Arceuthobium*) infection after six operational prescribed underburns in New Mexico. Survival 3 years postburn for 1,585 trees fit a logistic relationship with crown scorch, bole char, and mistletoe. The scorch effect was best represented by classes as <90, 90, and 100%; char as char-squared; and mistletoe as DMR < 5, 5, and 6. Survival ranged from over 90% for trees with DMR < 5 and scorch < 90% to almost 0% for trees with DMR 6 and scorch 100%. The proportion of surviving infected trees with reduction in DMR (scorch pruning) increased linearly with scorch. Reductions in average DMR (sanitation) from mortality and scorch pruning were observed on 12 of 14 plots and were associated with average scorch above 25%. A sanitation model estimated DMR reduction of 0.7 with 50% average scorch and initial average DMR of 3.0. Relative risk from scorch, char, mistletoe, and drought for up to 10 years postburn was assessed with proportional hazard models. Results indicate that underburning can be a viable tool to manage dwarf mistletoe, given sufficient fire intensity.

Keywords: dwarf mistletoe, prescribed fire, fire effects, *Arceuthobium*, *Pinus ponderosa*

Because of their widespread distribution and effect on productivity, dwarf mistletoes *(Arceuthobium* spp.) have long had an inseparable relationship with forest management in the western states (Geils and Hawksworth 2002). After decades focused on silvicultural control (which had varied success), came new emphasis on biodiversity and other noncommodity values; as a result, management of dwarf mistletoes on public lands became an uncertain and often contentious issue (Conklin 2000). Over a century of fire exclusion, however, has likely resulted in greater abundance of these forest pathogens (Tinnin 2003, Shaw et al. 2004).

Although fire is recognized as an important natural control of dwarf mistletoe (Hawksworth 1961), little quantitative information is available on this subject. Zimmerman and Laven (1984) and Kipfmueller and Baker (1998) showed approximately inverse relationships between fire frequency and dwarf mistletoe (*A. americanum*) severity in lodgepole pine forests of Colorado and Wyoming. In this forest type, where stand-replacing fires dominate fire history, trees often return to burned sites well prior to the mistletoe (Alexander and Hawksworth 1975). Initial use of prescribed fire to manage dwarf mistletoe focused on intense, stand replacement fires to eliminate the pathogen before regeneration (Baranyay and Smith 1972, Alexander and Hawksworth 1975). Less intense, "incomplete" burns were assumed to favor mistletoe over time (Alexander and Hawksworth 1975).

A better understanding of natural fire regimes (Weaver 1951, Swetnam 1990) led to interest in low-intensity fire as a tool for managing dwarf mistletoes, especially in ponderosa pine forests of the interior West. Koonce and Roth (1980) and Harrington and Hawksworth (1990) demonstrated a reducing effect of underburning on western dwarf mistletoe (*A. campylopodum*) in central Oregon and southwestern dwarf mistletoe (*A. vaginatum* subsp. cryptopodum) in northern Arizona, respectively. Both of these early studies involved relatively small samples of fire-scorched trees observed about 1 year postburn. Longer monitoring of three burned areas in northern New Mexico provided a more recent estimate of this reducing effect (Conklin and Armstrong 2001).

We present results from six, operational, prescribed underburns in ponderosa pine (*Pinus ponderosa* var. scopulorum) stands conducted between 1995 and 1999 in New Mexico. We include more rigorous analyses of the burns described by Conklin and Armstrong (2001) and add results from three additional fires. Our objectives are to (1) describe tree survival after underburning relative to risk factors including scorch and mistletoe, (2) quantify scorch pruning, and (3) assess potential for reduction in average mistletoe severity (sanitation). In this phase of a continuing, long-term study, we focus on tree survival for 6–10 years postburn and on changes in mistletoe severity at 3 years postburn.

Methods

Sites and Sampling

Five sites were monitored in the Jemez Mountains of northern New Mexico, and one in the Manzano Mountains of central New Mexico. Each site was predominantly ponderosa pine and mostly second growth. Most trees were 50–90 years old, with scattered older trees on some sites. Stands were typical of the accessible pine type in the Southwest and included areas recently thinned and others not thinned for over 20 years (Table 1). Elevations ranged from 7,200 to 8,400 ft; site indices ranged from about 60 to 80 ft at 100 years; plant associations included pine–Gambel oak and pine–bunchgrass communities.

At five sites, rectangular plots were installed before fire in areas with uniform stand structure and where a majority of trees were infected with mistletoe. Most plots included a minimum of 100 sample trees. The number of plots (1 to 3) per site and plot area

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Table 1. Initial characteristics of sites monitored for tree response to prescription burn.

Site	# Trees (plots)	Last thinned (yrs)	Fuel model[1]	Density (trees/ac)	Basal area (ft^2/ac)	QMD[2] (in)	% Trees mistletoe infected	Month and yr burned
1-RD 145	415 (3)	12	9	259	100	8.4	82	Oct 1995
2-Blanco	134 (1)	12	9	268	84	7.6	90	Mar 1996
3-San Juan	196 (3)	20	9	228	120	9.8	87	Sep 1998
4-Alamitos	262 (2)	1	12	37	27	11.5	64	Oct 1997
5-Manzano	248 (2)	1	12	120	63	9.8	72	Nov 1999
6a-Stable 1	114 (1)	3	9 & 12	109	54	9.5	54	Oct 1999
6b-Stable 2	101 (1)	22	9	240	110	9.2	91	Oct 1999
6c-Stable 3	115 (1)	22	9	250	120	9.4	96	Oct 1999

[1] Fuel model: 9 = timber litter, 12 = timber slash
[2] Quadratic Mean Diameter

varied with mistletoe distribution and stand density (Table 1). Sampling at the remaining site (Manzano) used these criteria but was opportunistic, with plots installed a few months after fire; preburn mistletoe ratings were estimated then. Plot selection and design were consistent with standard, westwide network of plots for monitoring behavior and impacts of dwarf mistletoes (US Forest Service 2007). All live ponderosa pine ≥4.0 in. dbh were tagged, measured for dbh (nearest 0.1 in.), and rated for dwarf mistletoe infection using the six-class Dwarf Mistletoe Rating (DMR) system (Hawksworth 1977). Crown class (dominant, codominant, intermediate, and suppressed) was rated where crown stratification was evident, i.e., on plots not recently thinned. Our sample included 1,585 trees on 14 plots (Table 1). Each plot had broad distribution of mistletoe severity, as indicated by standard deviations of mean DMR ranging from 1.4 to 2.1.

Fires and Assessment

Four fires were about 200 ac in size and hand ignited; the other two were larger burns that included hand and aerial ignition. Burn conditions are briefly characterized by stand structure, fuel model (Anderson 1982), and date of burn (Table 1). Fires were not shaped to kill or prune individual trees; therefore, any observed mistletoe reduction was a result of natural or chance distribution of the parasite and the scorch. The main objective of each burn was fuels reduction.

Crown scorch ratings were made a few months after each fire, before the flush of new growth. These were estimates, to the nearest 10%, of the proportion (length) of live crown scorched (Ryan 1982). Bole char was rated in 2004 as none (0), light (1), moderate (2), heavy (3), or severe (4) (Ryan 1982). Each site was revisited periodically for 6–10 years after fire to record tree mortality, including year of death and evidence of bark beetle attack. DMRs were retaken for live trees 3 years after fire (when fire-induced branch mortality had largely ceased), and on a 5-year cycle after plot installation. For consistency, all pre- and postfire DMRs, as well as crown scorch and bole char ratings, were made by the first author.

Fires on sites 1–5 burned at relatively uniform intensities, generating some crown scorch on most sample trees (Figure 1). These five sites were treated as core sites for all analyses. On site 6 (Stable Mesa), plots experienced either very low (<10% mean scorch) or uneven fire intensity; these were appropriately excluded from summaries of sufficient and even burns. Convective heating caused most scorch on all sites. Altogether, about 50 sample trees "torched" (16% of those with 100% scorch), and these had severe bole char.

Analyses

Data analyses were conducted using SAS Institute, Inc., program language and statistical procedures (version 9.1 for Windows 2004; SAS Institute, Inc., Cary, NC). Hypotheses and confidence limits used alpha at 0.05. Pearson correlation (r) and general linear models were used to describe relationships between crown scorch and various tree attributes. Plot-level summaries for percent survival by classes of scorch, char, and mistletoe severity were prepared with mixed linear models (PROC MIXED). Correlation among trees on the same plot was accounted for with a repeated-measures design (compound symmetry covariance structure) and fit with restricted maximum likelihood.

We screened several alternative sets and transformations of scorch, char, mistletoe, and dbh for preferred risk variables describing mortality. We used a general linear model (PROC GENMOD) to compute a logit function (a logistic model) for probability a tree was dead 3 years postburn. We adjusted for potential within-plot correlation using a repeated-measures design and assuming correlation structures for the binary responses are exchangeable. We used a proportional hazards model (PROC PHREG) for Cox regression (Allison 1995, SAS 2004) of tree death using the same factors identified in the logistic model. Cox regressions were also used to describe time dependencies of risk associated with scorch, char, mistletoe, and a 2002–2003 drought. The logistic and hazard models were assessed using residual analyses and statistics for significance of model and individual parameters, for improvement over competing models, and for goodness-of-fit, including c, an estimate of area under the response operator curve (SAS 2004).

Scorch pruning was assessed 3 years postburn and based on trees with observed reduction in DMR from preburn values. The percent

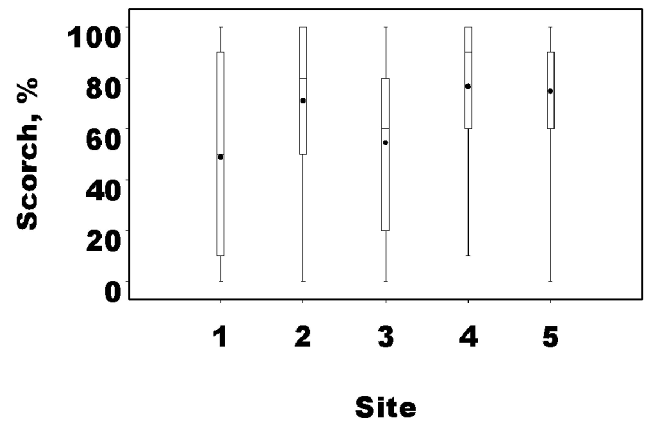

Figure 1. Distribution of crown scorch for trees on five, evenly burned sites (1–5). Box and whisker plots illustrate extreme values (whisker ends); 25, 50, and 75 percentiles (box ends and center line); and mean (dot). For site 5, the 50th and 75th percentiles coincide.

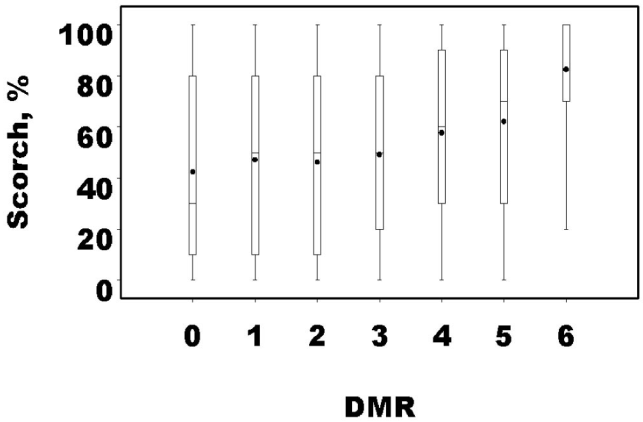

Figure 2. Crown scorch by DMR class for trees on three sites (1–3) not recently thinned. Box and whisker plots illustrate extreme values (whisker ends); 25, 50, and 75 percentiles (box ends and center line); and mean (dot). For DMR 6, the 50th and 75th percentiles coincide.

of trees scorch pruned and magnitude of reduction were modeled, respectively, as a linear function and a segmented linear function of scorch. Regressions were fit with a linear model (PROC REG). Observed reduction in average DMR (sanitation) was computed for all 14 plots as average DMR preburn minus average DMR postburn. Comparable expected reductions were computed by applying the logistic model for mortality and the scorch pruning models to trees on the 14 plots.

Results

Crown scorch was weakly correlated with dbh ($r = -0.10$) and DMR ($r = 0.08$) for 1,255 trees on core sites 1–5. Correlation of scorch and DMR was stronger ($r = 0.29$; $P < 0.001$) on sites not recently thinned (sites 1–3). Scorch increased in a nonlinear trend with mistletoe severity on each of these sites (pooled in Figure 2) but not on recently thinned sites 4 and 5 where slash was present and most heavily infected trees had been cut. Where crown stratification was evident (sites 1–3), scorch was significantly greater ($P < 0.0001$) on intermediate and suppressed trees (mean, 71; SD = 33) than on dominant and codominant trees (mean, 50; SD = 35).

Postburn Survival

After fire, core sites displayed steeply declining mortality for 2 years, followed by shallow, irregular mortality. Over a 6-year period, 395 of 1,255 trees died; of these, 77% died the 1st year, 88% within 2 years, and 90% within 3 years. Four of these five sites had no additional mortality the 3rd year after fire, suggesting that a 3-year period encompassed most fire-related mortality. Mean 3-year survival decreased with more severe levels of scorch, char, and mistletoe (Figure 3), with greater variation at higher levels of scorch (3A) and at high char (3B); variation within DMR classes (3C) reflected differences in fire intensity. A logistic model described expected probability of death within 3 years of fire for 1,585 trees on all six sites (Table 2). Stepwise regressions included parameters in the order: scorch, char, and mistletoe; backward selection removed dbh at $P =$ 0.11. A scorch effect was best represented by classes as <90, 90, and 100%; a nonlinear char effect by char-squared; and a mistletoe effect by classes as DMR < 5, 5, and 6. These parameters and an intercept term were significant ($P < 0.0001$). Residual plots revealed no

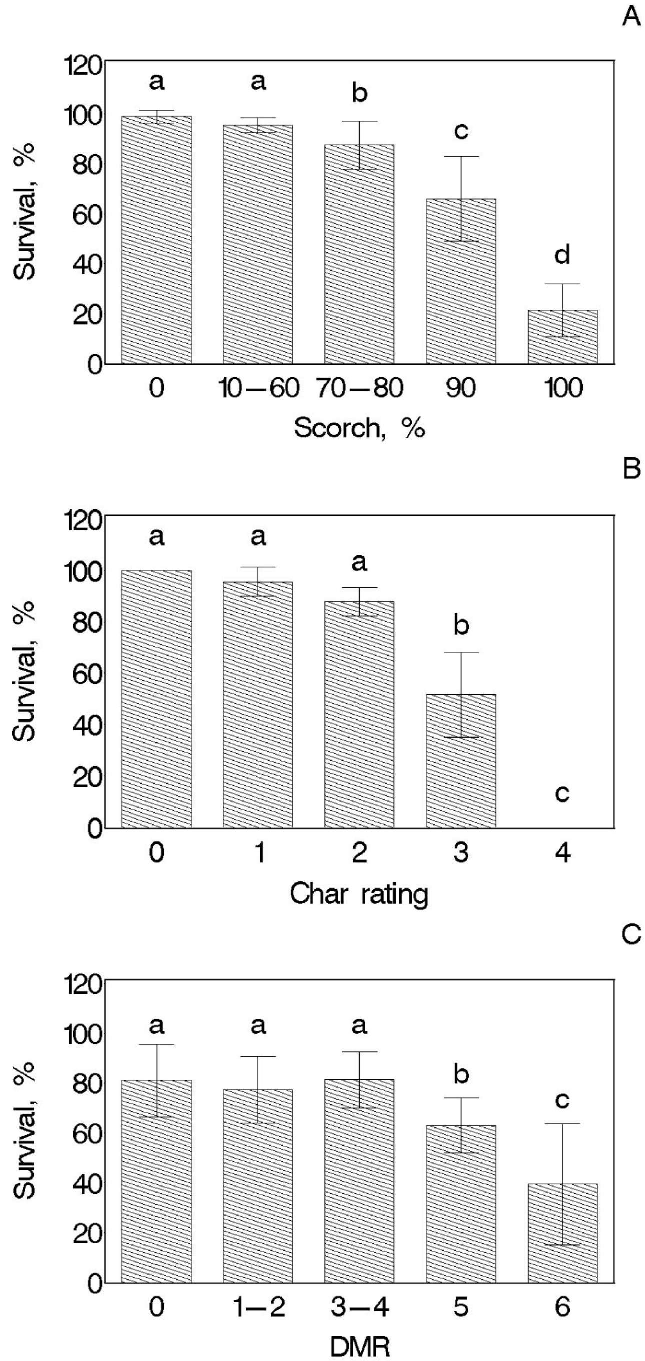

Figure 3. Mean survival (percent trees living 3 years postburn) for five sites (1–5) by (A) crown scorch, (B) char rating, and (C) DMR classes. Classes designated with the same letter are not significantly different; error bars indicate 95% confidence limit on the mean.

unacceptable patterns by site, dbh, crown class, scorch (0–100%), char, or DMR (classes 0–6); rank correlation was very high ($c >$ 0.91). By averaging observed survival for each scorch and DMR class (and likewise for expected survival), the effect of char was combined with the error term to permit a two-dimensional display of 3-year survival (Figure 4). Expected survival ranged from over 90% for trees with DMR < 5 and scorch < 90% to almost 0% for trees with DMR 6 and scorch 100%. Tree size (dbh) was correlated with other risk factors and not entered into the model with scorch,

Table 2. Models for likelihood of tree mortality after prescription burn on mistletoe-infested sites.

	Logistic†		Proportional hazards‡		
Parameter*	Estimate	Standard error	Estimate	Standard error	Hazard ratio
Intercept	−4.4610	0.2182			
If Scorch is 90%	1.6827	0.2526	0.88319	0.14237	2.419
If Scorch is 100%	3.5171	0.3847	2.50902	0.12874	12.293
Char-squared	0.2779	0.0437	0.18886	0.01651	1.208
If DMR is 5	0.8455	0.2461	0.73538	0.13077	2.086
If DMR is 6	2.3453	0.1838	1.85661	0.15908	6.402

$N = 1585$ trees on 8 sites; 411 dead at 3 yr and 483 dead at 10 yr.
* For crown scorch and DMR, variables assume values of 0 or 1; for bole char, rating value (0 to 4) is squared (0 to 16).
† Mortality as of 3 yr post-burn; logit link function; fit adjusted for plot effect; $P < 0.0001$, $c = 0.92$.
‡ Stratified by site for baseline hazard functions; $P < 0.0001$.

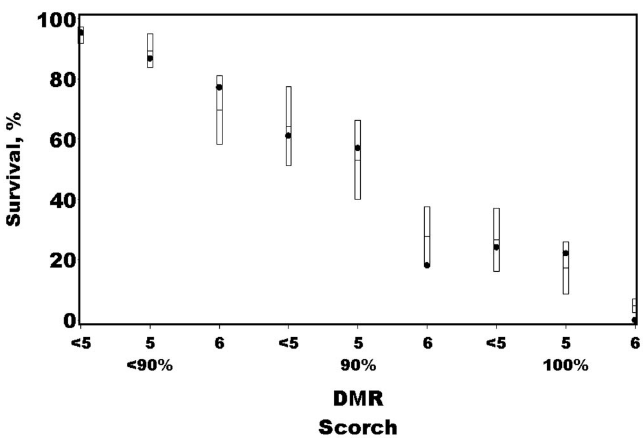

Figure 4. Tree survival 3 years postburn for 1,585 trees on six sites. Trees grouped by classes for crown scorch and DMR; bars (expected, ±95% CL) indicate survival modeled with a logistic function (Table 2); dots indicate observed mean survival for scorch–DMR class.

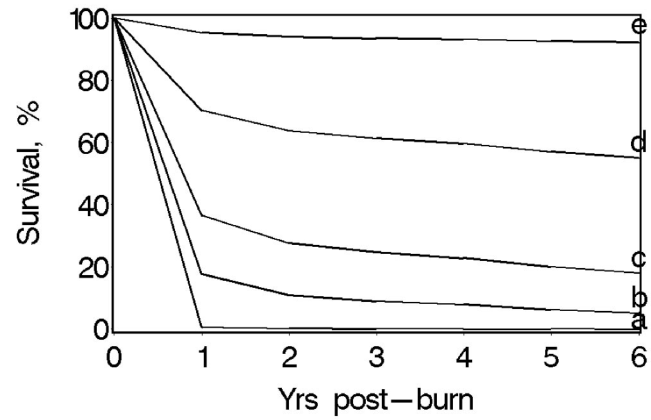

Figure 5. Expected survival for five classes of trees, over a 6-year postburn interval, estimated from a proportional hazards model. Survival is displayed for trees with (a) 100% scorch, char 3, and DMR 6; (b) 100% scorch, char 3, and DMR 5; (c) 90% scorch, char 2.5, and DMR 6; (d) 90% scorch, char 2.5, and DMR 5; and (e) less than 90% scorch, char 2, and DMR less than 5.

char, and DMR. However, across core sites, mean dbh of surviving trees was 1.2 in. (SE = 0.3) greater than those that died. Contrasts in average dbh between surviving and dying trees were greatest on sites not recently thinned; here as well, dominants and codominants survived better (86%) than intermediate and suppressed trees (62%). Each fire tended to provide a low thinning.

A proportional hazards model assessed relative risks of scorch, char, and mistletoe to longevity of 1,585 trees on all sites over a 6- to 10-year postburn period (Table 2). In contrast to the logistic model, which described survival to one point in time (Figure 4), the hazard model described change in survival over time (Figure 5). The same parameters used for the logistic model were also significant for the hazard model. Compared with a baseline hazard function (for scorch < 90%, char rating 0, and DMR < 5), a tree with 100% scorch had five times the risk of death as one with 90% scorch. A DMR 5 tree had about the same added risk as one with 90% scorch, and a DMR 6 about three times the risk of a DMR 5. Risk increased almost directly with the square of the char rating. The hazard model projected high survival (>95%) over a 6-year period for trees with scorch < 90%, char rating ≤ 2, and DMR < 5. It predicted high, early mortality (>95%) for trees with 100% scorch, char rating ≤ 3, and DMR 6. Intermediary survival was estimated for other combinations of these risk factors (Figure 5). Modifications of the hazard model also assessed an additional effect of drought (years 2002 and 2003), persistence of scorch and char effects, and an early mistletoe effect. Although the fires occurred in different years (Table 1), risk increased in 2002 and 2003 (hazard ratio, 6.2; $P < 0.0001$). Crown scorch was not a risk factor after 3 years postburn, and bole char continued to be significant 4–6 years postburn (hazard ratio, 1.1; $P = 0.004$). DMR 5 provided significant risk (hazard ratio, 1.5; $P = 0.003$) and DMR 6 very significant risk (hazard ratio, 4.0; $P < 0.0001$) even during the initial 3 years.

Scorch Pruning

Among 913 infected trees surviving the fires on all sites, 305 (33%) exhibited scorch pruning, i.e., observed DMR 3 years after fire was less than before fire. On the more uniformly burned core sites 1–5, 295 trees (42%) were scorched pruned. Regardless of site, 71% of these trees decreased one DMR class, and 29% decreased two or more classes. The proportion of surviving infected trees with scorch pruning increased with increasing scorch ($R^2 = 0.99$). At 30% scorch, about one-fifth were scorch pruned; this increased to about one-half at 60% scorch (Figure 6). Above 40% scorch, an increasing proportion of trees decreased more than one DMR class ($R^2 = 0.83$), providing greater average reduction (Figure 6). Residual analyses indicate these relations were largely independent of site, dbh, and initial DMR.

Reduction in Average DMR (Sanitation)

Average DMR 3 years after fire decreased on all plots (Table 3), except the two lightly burned plots on site 6. Reductions resulted from biased mortality and scorch pruning; scorch pruning was the

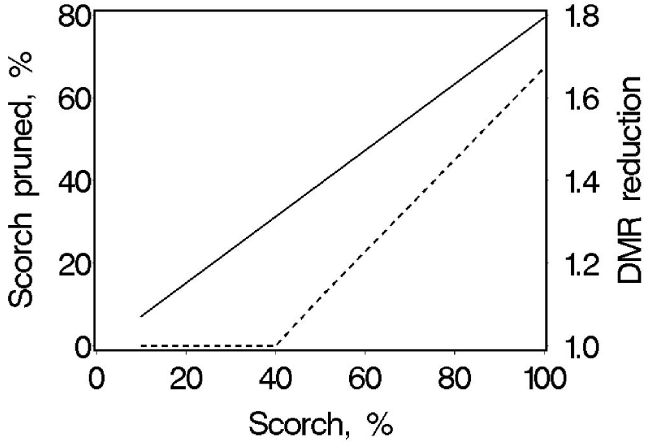

Figure 6. Proportion of initially infected, surviving trees with reduction in DMR after fire (——) and expected reduction in DMR (- - - -) of trees for which DMR decreased. Based on 913 surviving infected trees on six sites, 3 years after fire.

greater contributor on the majority of plots. Reduction increased with increasing average crown scorch and average DMR before fire. The combined logistic model for survival and linear models for scorch pruning determined expected plot-level reductions that correlated well ($r = 0.95$) with observed reductions (Table 3). Expected reductions were positive above average DMR 1.0 and 25% average scorch and increased to 1.2 for an initial DMR of 4.5 and 85% average scorch (Figure 7).

Discussion

Survival of ponderosa pine after these six fires was similar to that reported in several previous studies (e.g., Harrington 1993 and McHugh and Kolb 2003), except for the influence of heavy dwarf mistletoe infection. Survival was high among trees with less than 90% crown scorch, with large decreases at both 90 and 100% scorch. Most mortality occurred within 3 years of fire, although risk from bole char (confounded with drought) persisted 5–6 years. We observed signs of bark beetle (*Dendroctonus brevicomis* and/or *Ips* spp.) attack on about two-thirds of dead trees, both in the initial 3-year period and later. Although bark beetles clearly increased total mortality, their role as either causal or opportunistic mortality agent could not be determined for many trees. Immediate, postburn descriptors—crown scorch, bole char, and mistletoe severity—explained most of our observed mortality. A proportional hazards model supported a logistic model in explaining mortality and described longer-term risk.

Like Harrington and Hawksworth (1990), we found that dwarf mistletoe infection reduces survival of scorched trees. However, these authors assumed an increasing, linear effect throughout DMR classes, and concluded that heavily infected trees with moderate scorch have one-half the probability of survival of similarly scorched uninfected trees. We observed that—at any given scorch—lightly and moderately infected trees were no more likely to die than uninfected trees. DMR 5 trees showed a slight effect, and DMR 6 trees showed a more substantial effect, especially at high (≥90%) scorch. At moderate scorch, the effect was significant but not dramatic: within a range of 40–80% scorch, survival (3 years postburn) of DMR 5 and 6 trees was 88 and 71%, respectively, versus 93% for all other trees. However, among trees with 100% scorch, 47 (24%) of our DMR 0–4 trees survived, while all 52 DMR 6 trees died. Additional stress from severe mistletoe infection could explain increased death among fire-damaged trees.

This effect, described by the logistic model—along with a trend of increasing scorch with increasing DMR—results in a tendency for reduction in average DMR, via tree mortality, after underburning. Increasing scorch with increasing DMR, also reported by Harrington and Hawksworth (1990), is most likely a result of reduced self-pruning of lower branches and reduced height growth on infected trees (Hawksworth 1961, Godfree et al. 2002). Increased fuel loading within infested areas (Koonce and Roth 1985) also may contribute to this pattern. In recently thinned stands, slash may be a predominant fuel, which may obscure scorch–DMR relations. Scorch pruning can provide additional reduction in average DMR and may be the greater contributor in most underburns.

This study provides the best available estimate of scorch pruning. Previous reports (Koonce and Roth 1980, Harrington and Hawksworth 1990) assumed that most infected trees with 30–50% crown scorch would be scorched pruned, because dwarf mistletoe tends to be most prevalent in the lower crown. Our observations provided a lower estimate (Figure 6), because usually about one-half the scorched portion on our sample trees survived—along with any mistletoe present—due to bud survival. Our estimate is conservative because some new mistletoe plants became visible between pre- and postburn ratings; nonetheless, it seems unlikely that more than

Table 3. Reduction in average DMR 3 yr after under-burning.

Site	Plot ID	Average DMR, Pre-burn	Average scorch (%)	Observed reduction*	Expected reduction†
1-RD 145	11	2.4	28	0.12	0.29
1-RD 145	12	4.3	63	0.88	0.91
1-RD 145	13	2.2	57	0.40	0.35
2-Blanco	21	3.8	71	1.43	1.15
3-San Juan	41	2.6	27	0.16	0.32
3-San Juan	42	3.0	66	0.66	0.64
3-San Juan	43	2.1	68	0.45	0.37
4-Alamitos	31	1.9	77	0.38	0.45
4-Alamitos	32	1.2	77	0.17	0.24
5-Manzano	81	3.1	63	0.77	0.83
5-Manzano	82	1.7	85	0.37	0.38
6a-Stable	51	1.4	1	-0.12	0.01
6b-Stable	61	2.8	9	-0.22	0.10
6c-Stable	71	3.3	65	0.41	0.70

* Average DMR observed before the burn minus average DMR 3 yr post-burn.
† Average DMR observed before the burn minus average DMR expected 3 yr post-burn, using models for expected mortality (logistic) and scorch pruning.

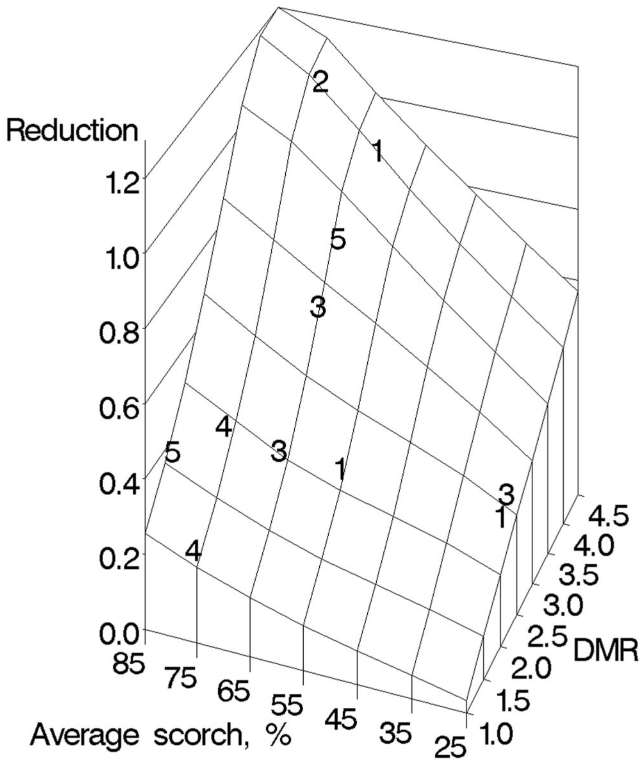

Figure 7. Expected reduction in average DMR (sanitation) for groups of trees 3 years after fire. Surface is reduction determined by computation of expected mortality (logistic model, Table 2) and expected scorch pruning (Figure 6) for tree distributions of scorch, char, and DMR observed on 14 plots (Table 3). Labels map plots on core sites 1–5 (Table 1).

one-half the infected trees with 50% scorch will have reduced DMR in any given fire. Note that nearly all reductions in tree DMR resulted from "lifting" of the live crown; heat alone appeared to have little effect on mistletoe shoots.

In a broader sense, scorch pruning is any fire-induced mortality of infected branches, regardless of effect on DMR. Scorch pruning will tend to improve host vigor, as well as reduce reproduction and spread of mistletoe; however, severely scorched trees will experience growth loss, offsetting some of these gains. Long-term effects of scorch pruning will vary from tree to tree. Scorch itself, by lifting the crown, can reduce potential for new infections. On recently infected trees, scorch can eliminate latent infections (i.e., new infections without visible shoots), preventing or delaying mistletoe development.

The sanitation model (Figure 7) explained observed reduction in average DMR on most plots (Table 3). The greatest observed reduction (1.4), on site 2, was more than expected (1.1) and may indicate how much sanitation is possible without actively shaping fire to kill and/or prune-infected trees. On site 6c, uneven fire intensity explained the relatively large difference between observed (0.4) and expected reduction (0.7). The model fit well with independent data from 191 trees in Arizona (Harrington and Hawksworth 1990), observed 4 years postburn. Prescribed fire on this Grand Canyon plot generated average crown scorch of 42% in trees with average preburn DMR of 3.6. Observed reduction was 0.5, equal to the model's expected reduction.

Similar reductions in average DMR may be obtained in other ponderosa pine stands in the Southwest and Rocky Mountain regions after prescribed underburning. Because our fires were not intentionally shaped for mistletoe control, comparable reductions might be expected in wildfires and prescribed natural fires (or portions of these) of relatively low intensity. Our six fires were conducted during dormant seasons; lower survival could be expected in summer burns (Harrington 1993). The sanitation model predicts reduction in average DMR within infested portions of stands. Because of spread from ballistic seed (with limited range), dwarf mistletoes usually have patchy distributions within stands and across larger landscapes. The potential for reduction in any given area will necessarily depend on the proportion of the area infested and the coverage and intensity of the fire. Most stands with light infestation include areas without mistletoe; potential for reduction in these stands is less than in those with heavier, more extensive infestation. Similarly, sanitation in recently thinned stands may be less than in others, because thinning itself often reduces average DMR. Nonetheless, underburning in both lightly infested and recently thinned stands can potentially set back mistletoe for several years.

Although its controlling effect is more modest than previously suggested, our results indicate that underburning can be a viable tool for managing dwarf mistletoe. Results to date suggest that a uniform burn generating 50% average crown scorch can provide 10–12 years of control, i.e., 10–12 years of stand growth before mistletoe returns to its preburn level. Although mistletoe control usually is not the primary objective of prescribed burning, relations between fire and mistletoe should be considered in prudent land management. A century of fire suppression/exclusion has favored dwarf mistletoes. Many ponderosa pine stands in the Southwest (and perhaps elsewhere) could benefit from broadcast burns generating 30–60% average crown scorch. As noted by Harrington (1993), concerns over fire control and undesirable effects influence its use; as a result, prescribed fires often do not accomplish management objectives or provide substantial ecological benefit. Burns generating little or no crown scorch have little or no effect on mistletoe; similarly, burns of such low intensity may have relatively little effect on fuels, fire hazard, or other forest conditions.

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