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Title: INTERACTIONS BETWEEN FIRE AND DWARF MISTLETOE IN PONDEROSA PINE

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THE EFFECTS OF DWARF MISTLETOE ON FUEL IN PRECOMMERCIAL PONDEROSA PINE STANDS

Dwarf mistletoe and healthy stands were sampled by vertical planar intercept and whole tree biomass sampling techniques to measure fuel loading in ground and crown fuels. Differences in size, distribution, and vitality of fuel were shown to depend on stand structure and disease expression parameters.

THE EFFECTS OF PRESCRIBED BURNING ON DWARF MISTLETOE IN PONDEROSA PINE

Eight understory prescribed burns were examined in two locations before and after burning for changes in dwarf mistletoe vitality and distribution. Mistletoe reduction resulted from killing infected understory trees, and "pruning" dwarf mistletoe plants and infected branches from crop trees. The degree of sanitation was related to fire severity, original levels of mistletoe infection, stand structure and fuel conditions.

# INTERACTIONS BETWEEN FIRE AND DWARF MISTLETOE IN PONDEROSA PINE

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# INTERACTIONS BETWEEN FIRE AND DWARF MISTLETOE IN PONDEROSA PINE

## INTRODUCTION

Historically both fire and dwarf mistletoe (*Arceuthobium campylopodum* Engel.) have influenced the development of the ponderosa pine (*Pinus ponderosa* Laws.) forest on the east slope of the Cascade Mountains. The frequency of past fires may be estimated from stumps of fire scarred old-growth pines while severity can be judged from the degree of destruction and structure of burned stands. Where fires were severe, mistletoe is limited or absent from the residual or replacement forest.

Ponderosa pine is very susceptible to dwarf mistletoe (Roth 1971, 1974). Because of limitations on dispersal of its heavy seeds, it lacks the general type of resistance that trees commonly develop to diseases caused by widespread airborne inoculum. By burning out and replacing old, infected stands, fire rather than inherent resistance to infection, has kept mistletoe at moderately low levels in the past (Hawksworth 1961, Roth 1953). Conversely Roth (1966) has hypothesized that fire has prevented genetic development of general resistance to mistletoe by burning progeny naturally selected for resistance in severely infected areas.

Mistletoe greatly modified stands that were heavily infected and in so doing indirectly influenced fire (Weir 1961a, 1961b). Infected trees were shorter and stockier than healthy trees (Childs and Wilcox 1966, Shea 1974). Their branches consequently were nearer the ground. Trees of pole size and larger frequently developed brooms of small, often resinous branches along their boles. Large brooms in mature timber sheared from the trees under the weight of snow and ice to accumulate on the ground as dense masses of dry, fine fuels in contrast to normal scattered limbs of large trees. Dead brooms remaining along the boles provided ladders of fine fuel facilitating crown fires (Weir 1961a). Also, general decadence of infected stands appeared to increase the ratio of dead to living wood.

Under management that includes fire control, timber harvest and stand improvement the relationship between mistletoe and the infected stands has changed greatly. Fire control has allowed mistletoe to increase but selective logging and cutting have offset these losses. Heavily broomed old growth was taken in the earliest cuts with infected trees being regularly removed during subsequent entries. Young stands with mistletoe have been treated for mistletoe control during thinning or have been replaced entirely. Nevertheless, mistletoe is still prevalent in the forest and it is reasonable to ask how fire and mistletoe are interacting under existing and anticipated conditions of management.

The ability to characterize fuels in infection centers will enable forest managers to know whether or not infected areas are likely to have distinctive burning characteristics which call for special treatment in prescribed burns. Since fire has controlled mistletoe under natural conditions and has potential for control under management, a quantitative expression of the influence of mistletoe on fuel can be used in a fuel formula for prescribed burning where mistletoe reduction is an objective of the burn.

It is also necessary to conduct prescribed burns under different stand conditions and levels of mistletoe severity. A variety of administrative objectives may be met by altering the burn prescription to provide the necessary level of sanitation. This may vary from scorch pruning the lower crowns to complete sanitation after salvage of badly infected stands.

The focus of this research program was on young stands of precommercial saplings and small pole-sized timber with variable mistletoe intensity ranging from no apparent infection to severe infestation. Stands were measured to evaluate the effects on fuel within "time lag" size classes (diameter classes of fuel relating to equilibrium moisture contents). Next comparable diseased and healthy stands were burned by low and high intensity ground fires. Stands were then evaluated for the degree of mistletoe reduction in crop and non-crop trees as a result of "scorch-pruning" and mortality of infected trees.

# THE EFFECTS OF DWARF MISTLETOE ON FUEL IN PRECOMMERCIAL STANDS OF PONDEROSA PINE

## INTRODUCTION

Dwarf mistletoe (Arceuthobium campylopodum Engelm.) is a widespread and damaging parasite of ponderosa pine (Pinus ponderosa Laws.) causing growth loss, distortion, and death of parasitized trees. Heavily infected stands are so modified that fuel characteristics and consequently flamability are affected (Weir 1916a, 1916b). Infected trees are shorter and stockier than healthy trees (Childs and Wilcox 1966, Shea 1964), and consequently their branches are closer to the ground and more exposed to ground fire. Trees of pole size and larger frequently develop brooms with many small, pathologically resinous branches along their boles. Large brooms in mature timber shear from the trees under the weight of snow and ice to accumulate on the ground as masses of dry, compact fuels, in contrast to the scattered distribution of limbs of normal trees. Dead brooms remaining along the boles provide stairs of fine fuel facilitating crowning of fires (Weir 1916a). Also, general decadence of infected stands appears to increase the ratio of dead to living wood. Under a management program that includes mistletoe control these parasitized trees are removed. However, under present conditions of young growth management infected trees are often needed to meet stocking and spacing requirements. Thus, it is reasonable to ask how dwarf mistletoe affects routine management--including prescribed burning--of sapling and pole-sized stands. The effects of mistletoe on fuel are examined here.

The ability to characterize fuels in dwarf mistletoe infested stands will enable forest managers to know whether or not infested areas are likely to have distinctive burning characteristics which call for special prescriptions in fuel treatment, site preparation, and understory burning programs. Natural fire has historically controlled mistletoe (Hawksworth 1961, Roth 1953) and fire has potential for control under prescription. However, the basis for interaction between fire and mistletoe has been considered only rarely, and prescribed burning has had only limited use for mistletoe control (U.S.D.A. Forest Service 1973). Currently a quantitative expression of the influence of mistletoe can be used in fuel evaluation for prescribed burning whether or not mistletoe reduction is an objective of the burn.

For quantitative study we must have means of expressing both mistletoe severity and fuel characteristics including fuel loading, distribution and type. Several methods are available for evaluation of mistletoe severity (Roth 1952, Wilcox 1963, Hawksworth and Lusker 1956). All depend heavily on frequency of infection and imply the nature of damage to be a reduction in productivity as infection numbers increase. The Hawksworth method is most used and is suitable where broad severity classes describe the level of infection. However, since it fails to consider crown deformity it is not completely suitable for descriptions of individual trees or stands in terms of fuel characteristics.

Most studies of forest fuels have concerned surface fuels (Bailey 1969, 1970; Brown 1974; Brown, Snell, Burnell 1977; VanWagner 1968, among others) which consist of normal forest litter or litter combined with logging slash. These methods are appropriate when applied to areas of mistletoe infestation in old timber where most of the fuel within reach of a surface fire consists of fallen brooms and fallen deformed dead trees. These procedures should also apply to silviculturally improved young stands where wood has been brought to the ground by thinning. For infested natural young stands nearly all of the wood modified by mistletoe remains on the trees and yet is within reach of a surface fire. The standard planar intersect procedures may be modified in order to sample this material also.

Predictive models for aerial fuel have been developed for healthy crowns by either employing a geometric crown form (Sando and Wick 1972), or applying regression techniques relating basal area and other tree parameters, notably sapwood area, to fuel amounts (Brown 1976, Baskerville 1965, Crow 1971, Grier and Waring 1974, Hann and McKenney 1975, Snell and Brown 1978).

## STAND SELECTION AND DESCRIPTION

The nature and wide extent of past stand alterations in the ponderosa pine forest type prevents investigation of the interaction of dwarf mistletoe and fuels in natural ecological conditions. Therefore stands for study were chosen as representative of existing management conditions and projected future management objectives. Areas with healthy and diseased parts were selected for internal uniformity of habitat, infection condition, and management history. Study plots were located in moderately dense patches of trees. This implied a somewhat artificially dense forest but served to exemplify the contribution of dwarf mistletoe altered biomass to fuel loading parameters where physically the trees, and fuels, hence were actually located. Stands with poor crown visibility due to high stand density or tall stands with crowns far above flame height of a surface fire, were excluded.

Most stands were located on the southwest to southeast exposure of buttes, notably reflecting the relationship of topography to mistletoe frequency and severity (Roth 1952, 1954a, 1954b). Harsh sites were avoided because of the confounding factors of suppression and competition with brush. Sites on north slopes and flat topography were densely stocked with trees, and were rarely so infected that crowns were modified.

Ponderosa pine was the dominant overstory species at all locations, with important understory vegetation consisting of *Ceanothus*, *Manzanita*, and *Purshia*. Stand locations included Pringle Butte, Cruiser Butte, Wampus Butte, and Lava Butte and Sun River (so named by their proximity to these locations) on the Bend Ranger District of the Deschutes National Forest in Central Oregon. All locations except Cruiser Butte Natural Area had had at least one entry for light harvest and the natural surface fuels were somewhat mixed with logging slash. Areas of incomplete overstory removal within stands were avoided for plot location.

## MEASUREMENT PROCEDURES

Fuel loading data were taken along transects by methods adapted from Brown (1974) in 36 healthy and 57 diseased plots. On each plot six vertical planar transects 20 meters long and 2 meters high were located parallel to each other at 2 meter spacing. Each plane was divided into sub-planes one-half by 2 meters each. Fuel intercepts were then dot tallied according to height above the ground, size class, vitality, and dwarf mistletoe infection. Depth of litter, duff, ground fuels, and shrub cover were also measured as intercepted. In each fuel measurement plot a prism cruise plot was taken to record tree and stand characteristics. Each sample tree was described as to position in canopy, bole diameter, total height, height to first live branch, crown width, and percentage of biomass alteration or "distortion" resulting from the mistletoe. Distortion was occularly estimated from crown form assuming that 66 percent of the biomass was located in the lower 55 percent of the live crown. Distortion was defined as that tissue which was swollen, shrunken, or misshappen due to infection and is expressed as percent of the crown involved. The volume of healthy branch tips and needles distal to infection were excluded. Trees were also given a "Hawksworth rating" which assigns a score from zero to six based on the amount of infection in each third of live crown length. Brooms and spindles were recorded by size and height in the tree.

In addition to data from the plots 21 trees from Pringle Butte were destructively sampled to determine distribution of biomass among various tree components. The tree crowns were initially divided into four horizontal sections: the lowest dead branches, and ascending thirds of the live crown. In each section branches were clipped into four time-lag fuel size classes (Brown 1974) and were described according to vitality and mistletoe infection; needle weight was later subtracted.

## RESULTS AND DISCUSSION

### Data from the "Prism" Plots

Mean values descriptive of the prism plots appear in Table I. The plots were quite varied in character. Wampus Butte and Sun River had widely spaced trees seven to eight meters in height. Cruiser and Lava Buttes contained more densely stocked stands of small trees from four to six meters in height. Cruiser Butte had the second lowest basal area and the highest number of stems per hectare; stagnation was evidenced by the slow growth of trees. Cruiser Butte often produced irregular values when compared to the other areas of plot locations. Analysis of prism plot and transect data emphasized the effects of stand structure on fuel distribution.

Averaging values for the Hawksworth mistletoe rating, distortion mistletoe rating, and for spindle and broom heights expressed as a percentage of total tree height, are listed in Table II for all areas combined. The increase in broom height relative to total tree height with increase in severity was slower than for spindles. Trees were young and closely spaced, conditions which do not favor rapid broom

TABLE I. MEAN STAND VALUES DESCRIBED BY THE PRISM PLOTS ON CRUISER, WAMPUS AND LAVA BUTTES AND SUN RIVER.

| | Location | | | |
|---|---|---|---|---|
| Stand Characteristics | Cruiser | Wampus | Lava | Sun River |
| Stems (S/ha) | 4,500 | 376 | 2,760 | 941 |
| Basal area ($m^2$/ha) | 21.7 | 20.5 | 35.4 | 30.6 |
| Stand height (m) | 4.1 | 8.2 | 6.4 | 7.1 |

development. In lightly infected trees these brooms are generally located in the lower whorl or two of branches in the live tree crown, often well below the average height of the bottom of the live crown which is about 35 percent of total tree height for a dense stand of small pole-sized trees. As broom frequency increases with mistletoe severity and tree age the location of brooms is elevated relative to tree height. Even so the values of 33 percent for heavily infected trees implies a significant extension of diseased branch biomass into the fire zone encompassing two meters above the ground.

Finally a fuel index variable was calculated by dividing the value for total aerial fuel by basal area for each disease severity class in each location. However, Cruiser Butte had a significantly higher (P = 90%) fuel index value for lightly infected plots than for other index values in that location. Since it was so unusual it was left out of calculations in some analyses for comparison (Table II).

TABLE II. MEAN VALUES DESCRIBING DWARF MISTLETOE CHARACTERISTICS IN STANDS DIFFERING IN MISTLETOE SEVERITY. A FUEL INDEX BASED ON TOTAL AERIAL FUEL WEIGHT DIVIDED BY BASAL AREA OF THE TREES IS ALSO GIVEN.

| | Hawksworth Rating | | |
|---|---|---|---|
| | 0-1.9 | 2.0-3.9 | 4.0-6.0 |
| Dwarf Mistletoe Characteristics | | | |
| Hawksworth rating | 0.5 | 3.1 | 4.8 |
| Distortion rating (%) | 0.7 | 15.2 | 33.0 |
| Spindle height (% tree ht.) | 34 | 54 | 53 |
| Broom height (% tree ht.) | 18 | 27 | 33 |
| Fuel Index[1] | 30.0 | 33.2 | 43.4 |
| Fuel Index[2] | 12.4 | 27.0 | 31.7 |

[1]See description of variable calculation in text.
[2]Calculated with the Cruiser Butte data excluded.

## Data from the Transects

Measurements of duff, litter, and depth of surface fuel were found to be significantly (P = 90%) higher in diseased stands where there was notable mortality compared to healthy stands. However, interception of such stands was infrequent.

No reliable fuel model could be established using regression techniques among the four study areas combined. Two way analysis of variance indicated a very significant difference (P = 99%) between study areas but generally was outside the 90 percent confidence limits for differences between infection levels across area. Stand height and stand density were most closely correlated with fuel in the two meter fire zone in all areas. However, more reliable models could be found when each area was divided into light, moderate, and severe disease classes roughly corresponding to Hawksworth ratings 0-1, 2-3, and 4-6 points. Each study area in turn had distinctive mistletoe and fuel characteristics which caused different variables to gain importance in the model. For instance, in heavily broomed areas broom height and volume were closely correlated with fuel loading. In dense stands the Hawksworth rating and stand height were more reliable. Since general applicability of the model was desired this approach was considered inappropriate, and one way analysis of variance was used to find significant differences in fuel size and distribution between disease classes.

## Effects of Dwarf Mistletoe on Surface Fuels

Surface fuel loadings are reported in Table III in tonnes per hectare and percent of total surface fuel loadings for all four areas combined. Three levels of mistletoe infection were selected as representative of stand conditions. Severely infected plots in both Lava Butte and Sun River had exceptionally high surface fuel loadings when compared to light and moderately infected plots. However, analysis of fuel loading in tonnes was not significant unless weighed by basal area. Results indicate a significant increase (P = 90%) in small fuels with increasing severity of infection. Fuel between 1 and 100 hour time lag size classes increased from 9 to 27 percent of total surface fuel loading in severely infected stands over corresponding healthy stands. There was a subsequent decrease in large fuel, greater than 7.6 centimeters in diameter, from 91 to 73 percent. This was primarily due to the contribution of 100 hour time lag fuels which increased 41 percent over the values for healthy stands.

TABLE III. COMBINED SURFACE FUEL LOADING DATA FOR CRUISER, WAMPUS, AND LAVA BUTTES AND SUN RIVER ARE GIVEN FOR INCREASING LEVELS OF DWARF MISTLETOE SEVERITY.

| | Dwarf Mistletoe Rating | | |
|---|---|---|---|
| Time Lag Size Class: | 0-1.9 | 2.0-3.9 | 4.0-6.0 |
| 1, 10 and 100 hour | | | |
| Tonnes per hectare | 3.4 | 5.4 | 7.0* |
| Percent of total | 9 | 8 | 27* |
| Large fuel | | | |
| Tonnes per hectare | 110.2 | 168.3 | 74.2* |
| Percent of total | 91 | 92 | 73* |

*Significantly different from healthy trees, P = 90%.

## Effect of Dwarf Mistletoe on Aerial Fuels

Aerial fuels comprised of branchwood intercepts within the two meter fire zone are reported in tonnes per hectare for all severity classes combined and in percentages of total fuel within disease severity classes (Table IV). The total aerial fuel ranged from 10.5 tonnes per hectare for lightly infected plots on Wampus Butte, the lowest density area, to 44 tonnes per hectare on Cruiser Butte in its most dense stands. Again the 100 hour time lag size classes were most significant (P = 90%) averaging 73 percent more fuel in tonnes per hectare than corresponding healthy stands (column 1).

The distribution of fuel among one-half meter divisions of the two meter fire zone was not significantly different (P = 90%) for different areas or infection levels. Healthy plots on Cruiser Butte had roughly 40 percent of fuel intercepts between the ground and one meter, and 60 percent between one and two meters. Diseased plots on Cruiser Butte had 43 percent and 57 percent located in the lower and

TABLE IV: COMBINED AERIAL FUEL LOADINGS ON CRUISER, WAMPUS, AND LAVA BUTTES, AND SUN RIVER BY LEVEL OF DWARF MISTLETOE SEVERITY.

| Time Lag Size Classes | Dwarf Mistletoe Rating 0-1.9 | 2.0-3.9 | 4.0-6.0 | 0-6 |
|---|---|---|---|---|
| | Percent of total aerial fuel | | | Tonnes/ha |
| 1 hour | 8 | 6 | 3 | 1.5 |
| 10 hour | 71 | 62 | 51 | 17.7 |
| 100 hour | 20 | 28 | 40* | 8.7 |
| Large fuel | 1 | 5 | 6 | 1.9 |

*Significantly different from healthy stands at P = 90%.

higher 1 meter divisions. In the other 3 areas the distribution for healthy plots was 25 percent in the first meter distance from the ground and 75 percent in the upper half. Diseased plots in the other areas had 34 percent and 66 percent in the lower and upper meter divisions of the fire zone. A 3 to 9 percent increase in fuel loading in the first meter of the fire zone is not statistically different from healthy stands but it does support the notion that fuel is brought closer to the fire in diseased stands. The variability of data from Cruiser Butte again emphasized the effects of stand structure on distribution of aerial fuels.

Cruiser Butte also differed from other areas with respect to vitality of the intercepted fuel (Table V). On Cruiser Butte intercepts in diseased stands were less vital than in healthy stands, whereas in the other three areas fuel intercepts in infected plots tended to be more vital than in healthy plots. This may be due to physiological changes in infected branches that allow them to resist

TABLE V. VITALITY OF BRANCHWOOD INTERCEPTS IN CRUISER BUTTE COMPARED WITH LAVA AND WAMPUS BUTTES AND SUN RIVER COMBINED.

| | Hawksworth Mistletoe Rating | | | | | |
|---|---|---|---|---|---|---|
| | 0-1.9 | | 2.0-3.9 | | 4.0-6.0 | |
| | Vitality | | | | | |
| | Live | Dead | Live | Dead | Live | Dead |
| | Percent | | | | | |
| Cruiser Butte | 48 | 52 | 40 | 60 | 36 | 64 |
| Other areas | 26 | 74 | 40 | 60 | 37 | 63 |

Values for healthy and diseased stands did not differ significantly at P = 90%.

natural pruning effects, as is also suggested by the average heights of brooms in infected trees relative to the bottom of the live crown in healthy trees reported earlier.

## Data from Crown Biomass Study

Crown biomass was examined to determine the amount and distribution of parasitized and healthy tissues in the crowns of dwarf mistletoe infected and comparably healthy crowns. Whole crown biomass data was expected to supplement the findings for aerial fuel loadings measured by the transects. The 21 trees selected for sampling on Pringle Butte were representative of those on the prism and intercept plots, particularly Lava Butte. They ranged from 1.5 to 17.8 centimeters in diameter and averaged 9 centimeters in dbh. Average height was 4.6 meters (Table VI). Trees were selected to provide a range of diameter and mistletoe severity and were grouped according to the latter characteristic. There was more consistency in the mistletoe classifications on Pringle Butte than in the prism plots, and as a

TABLE VI: AVERAGE DWARF MISTLETOE RATINGS AND HEIGHTS OF THE BOTTOM OF LIVE CROWNS FOR TREES ON PRINGLE BUTTE.

| Mistletoe Characteristics | Dwarf Mistletoe Rating 0-1.9 | 2.0-3.9 | 4.0-6.0 |
|---|---|---|---|
| Hawksworth | 0 | 2 | 5 |
| Distortion | 0 | 8 | 60 |
| Bottom of live crown (% of tree height) | 38 | 29 | 21* |

*Significantly different from healthy trees, P = 90%.

result Hawksworth and distortion mistletoe ratings were higher. A distortion of 60 percent is common for severely infected young trees; moderately infected trees will generally have distortion ratings of approximately 25 percent.

Distance to the bottom of the live crown was found to be significantly greater (P = 90%) in lightly than in severely infected trees. Moderately infected trees also showed a definite tendency to resist the effects of natural pruning as was found in the transect study. The average height of the crown base is about 35 to 40 percent of the total tree height for healthy trees in these stands. Low values support the belief that low hanging spindles and brooms remain vital and in parasitized trees bring the amount of aerial biomass closer to the fire than in healthy trees.

Branch and foliage biomass was also described as to its distribution within the crown. The crown was first divided horizontally into four sections. The bottom section contained dead branches only. The next section began with the bottom of the live crown and included the first third of the crown length. The third and fourth sections included the second and upper thirds of crown length. This manner of dividing the crown was consistent with the Hawksworth method used for mistletoe evaluation. Within each section healthy and diseased, vital and dead tissues were divided into size classes and weighed (Table VII).

TABLE VII. PERCENTAGE DISTRIBUTION OF BRANCH AND FOLIAGE BIOMASS WITHIN FOUR HORIZONTAL DIVISIONS OF THE CROWNS OF HEALTHY (OR LIGHTLY INFECTED) AND DISEASED TREES.

| Crown Section | Dwarf Mistletoe Rating 0-1.9 | 2.0-3.9 | 4.0-6.0 |
|---|---|---|---|
| | Percent | | |
| Dead branches below crown | 6.3 | 7.2 | 3.1 |
| Lowest one third | 37.9 | 32.5 | 45.3 |
| Middle one third | 39.4 | 41.3 | 43.1 |
| Upper one third | 16.4 | 19.0 | 8.5 |

The data indicate a tendency for concentration of biomass in the lower two thirds of severely infected trees, however, it is too slight at this point to be statistically significant. Note that these trees have comparatively little biomass in their upper crowns most of which is not infected even in severely infected trees. This is a significant consideration if trees are treated with high scorch heights in prescribed burns.

I next examined the separate distributions of healthy and diseased tissues within the crowns of healthy and diseased trees. In mistletoe infected trees 60 percent of the infected biomass was located in the lowest third of the live crown, followed by 39 percent in the middle third and 1 percent in the upper third. In contrast, healthy tissues in both healthy and diseased trees tend to follow a common distribution of 40 percent in the lower third, and approximately 42 percent and 18 percent in the middle and upper thirds, respectively (Table VIII).

TABLE VIII. THE DISTRIBUTION OF HEALTHY AND DISEASED TISSUES AMONG THIRDS OF THE CROWNS OF HEALTHY AND INFECTED TREES.

| Crown Section | Tissue: Tissue: | Diseased* Diseased | Healthy Diseased | Healthy Healthy |
|---|---|---|---|---|
| | | ---Percent--- | | |
| Lowest one third | | 60 | 40 | 40 |
| Middle one third | | 39 | 45 | 42 |
| Upper one third | | 1 | 15 | 18 |

*Tissues directly distorted by the parasite.

Diseased tissues were defined as those parts of the branch directly involved in spindling and brooming and did not include swollen branches with no apparent mistletoe infection. The amount of diseased tissue was found to be 30 percent in severely diseased trees and 10 percent in moderately infected trees. This does not correspond well with the occular estimates of 60 percent for severe trees, however, the distortion ratings were based on a much broader definition of mistletoe effects.

The effect of mistletoe infection also includes the swelling of infected branches relative to their healthy counterparts. Branch basal diameters were measured in healthy and infected branches in

TABLE IX. DIAMETERS OF HEALTHY (H) AND DISEASED (DM) BRANCHES IN THE CROWN OF HEALTHY AND DISEASED TREES.

| | Dwarf Mistletoe Rating | | | | |
|---|---|---|---|---|---|
| | 0-1.9 | 2.0-3.9 | | 4.0-6.0 | |
| Crown Section | H | H | DM | H | DM |
| | centimeters | | | | |
| Dead branches below | 0.8 | 0.7 | 1.4* | 0.6 | 0.9 |
| Lowest one third | 1.4 | 1.0 | 1.6* | 0.9 | 1.9* |
| Middle one third | 1.5 | 0.9 | 1.3* | 1.0 | 1.7* |
| Upper one third | 1.0 | 0.8 | | 0.8 | 1.0 |

*Significantly different than healthy counterpart, P = 90%.

healthy and infected trees, and are reported in Table IX. A significant increase in branch diameters of infected branches in diseased trees is indicated (P = 90%). Infected branches are almost twice the diameter of healthy branches in severely infected trees. Healthy branches are also notably smaller in infected trees than are corresponding healthy branches in healthy trees.

Vitality of crown biomass was also compared for healthy and diseased trees. The amount of dead biomass increased an average of two percent in moderately infected trees and four percent in severely infected trees over their healthy counterparts. Eight percent of the biomass was found to be dead in healthy trees. The most notable difference in vitality, however, was the increase in the length of the live crown as described above (Tables II and VI).

In order to quantify the fuel loading for branches and foliage in the crowns of healthy and diseased trees I developed regression equations based on tree diameters. Since the trees were already divided into classes based on mistletoe severity, mistletoe ratings did not contribute significantly to the accuracy of prediction. If all disease classes were combined this probably would not be the case, however, I did not have the computing power to test this assumption. Since the relationship between fuel and diameter was proportional I was able to improve the fit in some cases by natural log transformations: Ln (fuel) = a + b (ln dbh). Correlations were generally high except for the 100 time lag hour size classes where volume was low and variability was high. Variability was generally high for all analyses involving infected trees (Table X).

TABLE X. FUEL LOADING EQUATIONS FOR BRANCHWOOD AND FOLIAGE FOR HEALTHY AND MISTLETOE INFECTED TREES. FUEL VALUES ARE GIVEN FOR AN AVERAGE TREE, 9.0 CM IN DIAMETER AND 4.6 M IN HEIGHT. LN (FUEL) = A + B LN (DBH).

| Fuel Class | Mistletoe Rating | a | b | r | Grams |
|---|---|---|---|---|---|
| Branchwood | | | | | |
| 1 hour time lag | 0-1.9 | 2.60 | 1.80 | 0.98 | 703 |
| | 2.0-3.9 | 2.80 | 1.80 | 0.85 | 858 |
| | 4.0-6.0 | 3.88 | 1.28 | 0.82 | 806 |
| 10 hour time lag | 0-1.9 | 1.80 | 2.59 | 0.98 | 1,792 |
| | 2.0-3.9 | 1.74 | 2.70 | 0.98 | 2,148 |
| | 4.0-6.0 | 3.30 | 2.01 | 0.97 | 2,245 |
| 100 hour time lag | 0-1.9 | -1.14 | 1.52 | 0.45 | 9 |
| | 2.0-3.9 | -0.81 | 1.05 | 0.33 | 4 |
| | 4.0-6.0 | 0.47 | 2.19 | 0.39 | 197 |
| Needles | 0-1.9 | 3.42 | 1.99 | 0.99 | 2,422 |
| | 2.0-3.9 | 3.25 | 2.01 | 0.98 | 2,135 |
| | 4.0-6.0 | 3.11 | 2.01 | 0.90 | 1,856 |
| Total | 0-1.9 | 3.83 | 2.14 | 0.99 | 5,075 |
| | 2.0-3.9 | 3.85 | 2.16 | 0.99 | 5,410 |
| | 4.0-6.0 | 4.33 | 1.96 | 0.94 | 5,634 |

The equations in Table X predict fuel loading in grams based on diameter at breast height in centimeters. For illustration fuel is calculated for an average tree representative of the size sampled in this study. Results were also compared to equations by Cochran (unpublished data), Snell and Brown (1978), and Grier and Waring (1974) for calculation of ponderosa pine branchwood and foliage (Table XI).

TABLE XI. PREDICTIONS FOR BRANCHWOOD AND FOLIAGE IN PONDEROSA PINE FOR A SAMPLE TREE 9.0 CM DBH AND 4.6 M IN HEIGHT. BASED ON EQUATIONS AS CITED.

| Source | Branchwood | Foliage |
|---|---|---|
| | grams | |
| Snell and Brown (1978) | 1,763 | 1,725 |
| Cochran (unpublished) | 2,040 | 2,277 |
| Grier and Waring (1974) | | 8,778 |
| Koonce and Roth (1981) | 2,504-3,248 | 2,422-1,856 |

## CONCLUSIONS

Dwarf mistletoe affects both surface and aerial fuels in sapling and small pole sized stands of ponderosa pine. Most significant was the increase in fuel size. On the ground there was a 20 percent increase in the proportion of fine fuels to the total fuel weight. There was a marked increase in branchwood from 0.6 centimeters to 7.6 centimeters indicating that dwarf mistletoe infected branches had been brought to the ground either by logging or by natural pruning, and were persisting in the surface fuels. Branchwood intercepts measured in the two meter fire zone also indicated a significantly higher fuel loading in the 100 hour time lag size class. Measurement of branch basal diameters indicated averaged almost twice the diameter of healthy branches in the same tree and crown section, and were one and one-half times larger than corresponding healthy branches in healthy trees.

Infected branchwood may tend to persist in surface fuels both because of its increased diameter and because of its tendency to be abnormally resinous. An increase in the amount of fine fuels on the ground makes these stands more flammable and will tend to promote faster spreading and hotter fires than stands with a predominance of large fuel. The increase in diameter of vital infected branches remaining in the crown might tend to make these tissues less susceptible to fire effects but their thermal conductivity is unknown. Diseased branches are more succulent than healthy branches and have thicker phloem tissue which should increase resistance to heat injury.

The distribution of biomass within the crowns of diseased trees is also different than in healthy crowns. Even in these young stands severely infected trees had increased branch weight in the lower two thirds of the live crown. Also, mistletoe infected branches resisted natural pruning and significantly lowered the bottom of the live crown increasing the amount of fuel close to surface fires. Over half of the infected biomass in a diseased tree is loacted in the bottom third of the crown where it is most vulnerable to fire effects. Hot crowning fires should be sufficient to scorch much, if not all of the mistletoe infected branches and trees in such cases, despite any thermal protection the mistletoe might have evolved. The balance between fire intensity and mistletoe susceptibility is more complicated than what can be inferred from simple branch size and fuel distribution.

In understory burns where mistletoe reduction is an objective of the burn, a degree of mistletoe sanitation may be specified and scorch heights prescribed to promote pruning of branches at the desired height. The same height of scorch will remove more crown length in a diseased tree than a healthy tree of the same height. For instance, scorch heights aimed at pruning one third of the lower crown length of crop trees should result in a reduction of at least 60 percent of the mistletoe in a young stand with an average Hawksworth rating of 3. The degree of mistletoe reduction will be proportionate to mistletoe severity and degree of crown scorch. Stands which are burned at different states of development will provide various opportunities for mistletoe control, and sanitation may be progressive and cumulative.

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# THE EFFECTS OF PRESCRIBED BURNING ON DWARF MISTLETOE IN PONDEROSA PINE

## INTRODUCTION

Dwarf mistletoe (Arceuthobium campylopodum Engel.) is an endemic plant parasite which causes growth loss, distortion, and death of parasitized ponderosa pine trees (Pinus ponderosa Laws.). Direct losses in Oregon and Washington at one time exceeded 29 million cubic feet annually (Childs 1967), and mistletoe predisposes trees to other damaging agents. Mistletoe can, however, be tolerated in a stand if it is not severely damaging (Roth 1978). In undisturbed stands, dwarf mistletoe is in balance with its host, wide-spread but significantly damaging only on poor sites.

Fire and dwarf mistletoe interact with ponderosa pine in several ways. Mistletoe may influence the frequency of fire by making stands more flammable. Dwarf mistletoe infected trees are shorter and stockier (Childs and Wilcox 1966, Shea 1964). Their branches are often laden with resinous spindles and brooms which form fuel ladders leading to crowning fires (Alexander and Hawksworth 1975). Fallen brooms persist in slash, increasing the amount of large, resinous, partially rotten, highly flammable material. In decadent stands, dwarf mistletoe increases the amount of dry, dead aerial fuel.[1]

Prior to effective fire control, fire rather than inherent resistance to infection, kept dwarf mistletoe at moderately low levels (Roth 1953, 1966; Hawksworth 1961). Where fires were severe, dwarf

[1]Koonce, A. L. Unpublished data. Oregon State University

mistletoe is now limited or absent from the residual or replacement forest. Under management that includes fire control, timber harvest, and stand improvement, the relationship between mistletoe and pine stands has changed greatly. Fire control has allowed mistletoe to increase, particularly in young stands, while selective cutting in old-growth has offset the prevalence of mistletoe. Mistletoe control in young stands, either by thinning or by replacement, has had moderate success. Nevertheless, mistletoe is still prevalent and it is reasonable to ask how fire and dwarf mistletoe will interact under future intensive management.

Present control options include unit layout to treat infected portions of the stand, overstory removal, residual removal, sanitation thinning, stand replacement, species manipulation, or combinations of the above. Generally, reduction of lateral spread of mistletoe is the immediate goal with eradication to follow in subsequent rotations (Roth 1978). If height growth of the trees exceeds the vertical spread of dwarf mistletoe in its crown, a vigorous tree will "outgrow" the damage of the mistletoe.[2]

Prescribed burning has long been recognized as a tool for disease reduction during stand improvement (Weaver 1967). Fire has gained attention as a tool for site preparation, and as such, has been used to sanitize sites completely by burning the residual stand (Kimmey and Mielke 1959, U.S.D.A. Forest Service 1973, Muraro 1978). A review of fire and dwarf mistletoe (Alexander and Hawksworth 1975) summarizes

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[2]Barrett, J. W. Manuscript in preparation. U.S.D.A. Forest Service, Silviculture Laboratory, Bend, Oregon.

the effects of fire on dwarf mistletoe distribution. The effects of variable dwarf mistletoe severity on fire behavior are discussed as research needs.

The present study was designed to examine relationships between dwarf mistletoe reduction and fire intensity following prescribed understory burns in released (Kelsey Butte) or shaded understory (Pringle Butte) stands of ponderosa pine with different stand histories. We hypothesized that (1) dwarf mistletoe could be reduced by killing infected understory trees and scorch-pruning infected branches from crop trees, and (2) that dwarf mistletoe infected stands have distinctive burning characteristics.

## STUDY AREAS

One fall and seven spring prescribed understory burns were examined on Pringle and Kelsey Buttes near Bend in central Oregon. The sites are approximately 1,325 meters (m) in elevation and receive an average of 60 centimeters (cm) annual precipitation. The soils are Typic Cryandepts developed in Mt. Mazama dacite pumice deposited 7,300 years ago (Dyrness and Youngberg 1958). The vegetation is a transition between ponderosa pine/bitterbrush-manzanita, and ponderosa pine/ceanothus-bitterbrush habitat types (Franklin and Dyrness 1969). On Pringle Butte the Topography was gently sloping, under 10 percent, while on Kelsey Butte it exceeded 30 percent slope in some areas.

The Pringle Butte stand was characterized by patches of dense ponderosa pine regeneration, generally under 6 m in height. The Kelsey Butte stands consisted of thinned pole-sized trees averaging

17 cm dbh and 8.3 m in height. Both areas contained scattered old-growth overstory trees; however, these trees were not considered except to note any scorch in low hanging brooms. Pringle Butte surface fuel loadings were natural branches and twigs, pine needles, and scattered logging residue of mistletoe brooms and unsalvageable boles. Kelsey Butte had scattered aggregations of small-pole thinning slash approximately one-half m in depth and averaging 30 to 40 tonnes per hectare (ha). Shrub cover in both areas averaged 40 percent. The shrub canopy of ceanothus (*Ceanothus velutinus*), and manzanita (*Arctostaphylos patula*) ranged from an average of 70 to 125 cm in height on the two buttes.

## METHODS

Approximately one and one-half ha on Pringle Butte and 25 ha on Kelsey Butte were divided into blocks for prescribed burns and unburned controls. The Kelsey Butte burns were a part of a larger experiment conducted by the Silviculture Laboratory for stand improvement, particularly to reduce thinning slash and fire hazard. We sampled plot locations for the effect of the fires on the dwarf mistletoe populations in these blocks. Pringle Butte was selected to examine this relationship more intensively in unthinned stands. Young saplings and pole-sized trees on Pringle Butte had a wide range of dwarf mistletoe severity and appeared well suited for study of fire effects for reducing the disease by understory burning.

Circular plots of 5 m radius were evenly spaced through the burned areas in both locations. Surface fuel loading was calculated by the planar intersect method (Brown 1974), and shrubs by species and percent cover. Diameters and heights were measured for all trees. The following dwarf mistletoe characteristics were also recorded: the number of infected trees, and, for trees larger than 7.6 cm dbh, the Hawksworth severity rating (Hawksworth 1977), the percent of crown biomass distortion, the number of infected branches, and the number of dwarf mistletoe observed in each tree. All Pringle Butte plots and Kelsey Butte Block 2A were sampled before and after fires. The other Kelsey Butte blocks were sampled only after burning and the prfire parameters were estimated at that time. Unburned control plots were also sampled.

Spring burns were conducted shortly after snowmelt when warm dry weather allowed fire to spread in fine fuels. The fall burn was conducted in early September after summer temperatures had cooled and precipitation and humidity were increasing. Both locations were ignited by drip torch, and burned by backfiring and strip headfiring. On Pringle Butte some fire was shaped to destroy pockets of badly infected understory trees.

## RESULTS FOR UNTHINNED PLOTS

### Pringle Butte

Fires were set on May 15 and 25, and June 19, 1979, after two days of sunny weather. Burns were ignited during mid-day after drying of fine fuels. Humidity increased and temperatures cooled as the burns continued. Temperatures averaged 24° Celsius (C) with 24 percent relative humidity and variable winds averaging 10 kilometers (km) per hour with frequent gusts around 16 km per hour. A surface fire backed through brush and pine litter about 40 percent of the time, and flared up in patches of brush and dense trees in headfires about 60 percent of the time. Flame heights ranged from 15 cm in pine litter, to 60 cm in bitterbrush (Purshia tridentata), and to 180 cm in manzanita and ceanothus. Crowning, with flames to 10 m occurred in some trees. Overall, the flame heights averaged 35 cm in the May plots, and 85 cm in the June plots. Fire sperad averaged 90 cm per minute in May and 180 cm per minute in June.

Plots were separated into high- and low-intensity categories based on crown scorch and tree mortality (Table I). Mortality of understory and intermediate trees, expressed as a percent decrease in the prefire basal area, was significant on 59 percent of the Pringle Butte plots. Plots with basal area reduction of 40 percent or more were classified as high intensity fires. Low intensity fires reduced basal area less than 30 percent of the prefire value. The average basal area mortality for high and low intensity plots, respectively, was 56 percent and 33 percent. The percent reduction for low intensity plots was not significant at the 95 percent confidence level.

The amount of crown scorch was proportional to basal area reduction (Table I). Crown scorch is reported as a percentage of the original live crown height as measured from the initiation of the lowest live branch. The effects of scorch reduced the length of the live crowns by 21 percent and 56 percent in low and high intensity burns, respectively. The scorch height is an important parameter for the

TABLE I. MORTALITY, SCORCH-PRUNING OF CROWNS, AND REDUCTION OF SURFACE FUELS BY PRESCRIBED UNDERSTORY BURNING IN AN UNTHINNED STAND ON PRINGLE BUTTE. FIRE INTENSITY WAS BASED ON THE DEGREE OF MORTALITY AND SCORCH IN CROP TREES. REDUCTION IS EXPRESSED AS A PERCENT CHANGE FROM THE PREFIRE VALUE.

| | Prefire | Postfire | Change Percent |
|---|---|---|---|
| Basal Area ($m^2$/ha) | | | |
| High intensity fire (n = 17) | 99.1 | 43.2 | -56 |
| Low intensity fire (n = 12) | 61.0 | 40.6 | -33* |
| Lower Crown Height (m) | | | |
| High intensity fire | 2.6 | 5.3 | 103 |
| Low intensity fire | 2.8 | 3.8 | 36* |
| surface Fuel (tonnes/ha) | | | |
| High intensity fire | 40 | 16 | -60 |
| Low intensity fire | 43 | 8 | -82 |
| Shrub Cover (percent) | | | |
| High intensity fire | 23 | 1 | -96 |
| Low intensity fire | 40 | 8 | -80 |

*Not significantly different from prefire values at P = 0.05.

reduction of dwarf mistletoe in crop trees. Infected branches are scorch-pruned and thus mistletoe infections are proportionally reduced. The amount of mistletoe that was scorched depended on a variety of parameters, including the height of mistletoe in the canopy, the distribution and amount of mistletoe in the crown, and the amount of scorch that could be safely applied to the crowns.

Surface fuel was reduced from an average 41 tonnes to 13 tonnes per ha, 32 percent of the original level. Brush cover was reduced from 32 percent to 5 percent, and leaf area was reduced 85 percent over the entire stand. By the end of the summer, ceanothus was resprouting vigorously. Surface fuel and brush cover reduction did not correlate well with mortality of trees, partly because fuels and tree distribution varied widely. The open areas were brushy and contained several cull logs which increased the fuel loadings on these plots.

Table II shows trends between prefire basal area, postfire mortality, and the severity of dwarf mistletoe. Mistletoe populations build up rapidly in closely spaced trees when there is an inoculation source. This was noted in the distribution of prefire basal area and postfire mortality according to the dwarf mistletoe rating of plots. Severely infected plots with ratings of 3.6 to 6.0 were associated with plots with the highest average basal area. The lightly infected plots had low basal area reflecting the absence of host trees.

TABLE II. THE AVERAGE PREFIRE BASAL AREA AND POSTFIRE MORTALITY FOR DIFFERENT LEVELS OF MISTLETOE SEVERITY FROM UNTHINNED PLOTS ON PRINGLE BUTTE.

| Mistletoe Rating 0-6 | Plots n | Basal Area $m^2/ha$ | Mortality % |
|---|---|---|---|
| 3.5-6.0 (severe) | 9 | 134.4 | 56 |
| 0.5-3.0 (moderate) | 12 | 82.8 | 38 |
| 0.0-0.1 (light) | 8 | 17.5 | 50 |

The pattern of mortality for light, moderate, and severe dwarf mistletoe was also dependent on several variables. Severely infected patches were discriminated against by shaping fire. Moderately infected plots, with dwarf mistletoe ratings of 0.5 to 3.0, had lower intensity fires and 38 percent mortality. Only half of the lightly infected plots burned, but, because the trees were small and the plots contained many shrubs, tree mortality was 100 percent on those burned.

Dwarf mistletoe reduction resulted from thinning patches of severely infected trees, reducing the proportion of crop trees infected, and pruning infected branches from crop trees (Table III). The mortality of dominant, co-dominant, and intermediate trees greater than 7.6 cm dbh was significant after high intensity fires. The mortality of infected trees was 14 percent higher than that of uninfected trees. The number of trees on low intensity plots was not significantly different at the 95 percent confidence level from the prefire value, indicating little thinning. However, the decrease in infected trees was significant after burning. The proportion of infected trees was reduced from 79 percent to 59 percent for high intensity fires, and 35 percent to 26 percent for low intensity fires.

TABLE III. REDUCTION OF DWARF MISTLETOE IN AN UNTHINNED STAND ON PRINGLE BUTTE. FIRE INTENSITY WAS BASED ON THE DEGREE OF MORTALITY AND SCORCH IN CROP TREES AS SHOWN IN TABLE I. REDUCTION WAS BASED ON THE PERCENT DECREASE FROM THE PREFIRE VALUE.

| Plots (n =): | High Intensity Fire<br>17 plots | Low Intensity Fire<br>12 plots |
|---|---|---|
| | Reduction<br>Percent | |
| Crop trees | 44 | 8* |
| Infected trees | 58 | 31 |
| Infected branches | 68 | 35 |
| Mistletoe plants | 69 | 41 |

*Not significantly different from the prefire value at P = 95%.

Pruning resulted in a significant reduction in the number of infected branches in living trees (Table III). Because dwarf mistletoe infections are located predominantly in the lower crown, a large amount of infection can be pruned by the effects of heat and smoke from below. The numbers of infected branches remaining after high and low intensity fires were reduced by 68 percent and 35 percent of the prefire values, respectively. Burning sufficient to cause sanitation resulted in reduction in the number of infected trees in the stand as well as lowering dwarf mistletoe severity in infected trees.

The dwarf mistletoe severity rating is the sum of the ratings (0, 1, or 2) assigned to each third of the live crown depending on the proportion of branches in that third which are infected (Hawksworth 1977). Thus, the most severely infected trees may have a rating of 6. A severity rating of 3 is probably an unmanageable level for a young stand. This represents infection in more than one-half of the tree's branches and the level can be expected to increase significantly before harvest.

Scorch-pruning infected branches lowers the proportion of dwarf mistletoe in the crown and hence the severity and distortion ratings (Table IV). Because crown length is reduced when infected branches are pruned, reduction in the severity rating will occur only if the proportion of infected branches is decreased in the live crowns of the remaining crop trees. The mistletoe severity for high intensity plots was reduced from 3.8 to 2.0, roughly from two-thirds of the live crown length to one-third infected. This reduces a previously unmanageable level of dwarf mistletoe to a manageable level, as well as thinning

TABLE IV. FIRE EFFECTS ON DWARF MISTLETOE SEVERITY AND DISTORTION RATINGS FOR AN UNTHINNED STAND ON PRINGLE BUTTE. PREFIRE AND POSTFIRE RATINGS ARE GIVEN FOR TREES IN 2.5 CM DBH SIZE-CLASS INCREMENTS FOR HOT AND COOL FIRES. FIRE INTENSITY WAS BASED ON THE DEGREE OF MORTALITY AND SCORCH IN CROP TREES AS SHOWN IN TABLE I.

| dbh Size-class (cm): | 7.6 | 10.2 | 12.7 | 15.2 | Average |
|---|---|---|---|---|---|
| High Intensity (n = 17) | | | | | |
| Severity (0-6) | | | | | |
| Prefire | 4.0 | 3.7 | 3.3 | 4.0 | 3.8 |
| Postfire | 2.5 | 2.6 | 2.3 | 0.5 | 2.0 |
| Distortion (%) | | | | | |
| Prefire | 44 | 41 | 28 | 50 | 41 |
| Postfire | 21 | 33 | 15 | 3 | 18 |
| Low Intensity (n = 12) | | | | | |
| Severity (0-6) | | | | | |
| Prefire | 1.9 | 2.7 | 3.0 | 1.0 | 2.1 |
| Postfire | 1.9 | 1.1 | 0.0 | 1.0 | 1.0 |
| Distortion (%) | | | | | |
| Prefire | 23 | 21 | 15 | 20 | 20 |
| Postfire | 22 | 8 | 0 | 20 | 12 |

and releasing the remaining trees with less severe infection levels. The low intensity plots had less dwarf mistletoe originally, a moderate severity rating of 2.1. Scorching 21 percent of the crown length reduced the dwarf mistletoe rating to 1.0, a light amount. Another measure of mistletoe severity is the distortion percent, which is based on hypertrophy (or swelling) and alteration of crown from relative to a healthy tree. Distortion percent is calculated from the ratio of volume of biomass altered to total crown volume. Distortion is closely correlated with severity and will be reduced with mortality of infected trees or branches. The amount of distortion was reduced by half in both high and low intensity fires. Less than 20 percent distortion can be considered as manageable in treated trees (Table IV).

We also sampled the vitality of dwarf mistletoe aerial plant portions, immediately after burns in June, in late July, and in early September. The aerial parts of dwarf mistletoe plants dried and browned throughout the crowns during the summer. This resulted in setting back the life cycle of the parasite two years as seed development was prevented for the current year and pollination for the following year's crop was also prevented.

## RESULTS FOR THINNED PLOTS

### Kelsey Butte

Kelsey Butte was divided into different blocks for spring and fall burning. Spring fires were set on Kelsey Block 1E April 19, 1979 until stopped by snow and resumed May 3. Block 2A was burned May 4, 1979. The only fall burn, on Block 1B, was conducted September 5, 1979. Strip headfires were used, but fires were allowed to back into slash concentration or large shrubs, with some flare-ups occurring in these fuels. Average windspeed was 6 km per hour, temperatures averaged 12°C, and relative humidity averaged 45 percent. Dead and down fuels before burning ranged from 30 to 42 tonnes per ha and were reduced to 10-30 tonnes per ha, with the greatest reduction in the 1- and 10-hour timelag fuels. The dead and fine live fuels in shrubs, with up to 20 tonnes per ha, were largely removed. However, fire intensity was gauged adequately for the purposes of our study by scorch heights in the sample trees.

Tree size, density, and shrub cover were different for each block depending on its position on the slope. Block 1E was located on moderately sloping topography, and had mature and pole-sized trees averaging 18 cm dbh, 9 m in height, and approximately 5.5 m spacing with fairly even distribution of trees. The area was characterized by scattered light infections in the poles and moderate infection levels in the old-growth trees. Flame heights averaged 185 cm, and rate of spread averaged 67 cm per minute. Scorch was light, killing one or two branches in scattered trees without affecting the mistletoe population directly (Tables V and VI). Dwarf mistletoe brooms in old-growth trees were occasionally observed to be scorched through approximately the lower one-third of the broom, insufficient to cause death of the entire branch.

TABLE V. PREFIRE BASAL AREA FIRE CAUSED MORTALITY AND SCORCH-PRUNING OF CROWNS IN THINNED STANDS FOR SECTIONS OF KELSEY BUTTE.

| Block:<br>Plots (n = ): | 1E<br>6 | 2A<br>14 | 1B<br>14 |
|---|---|---|---|
| Basal area ($m^2$/ha) | 20.6 | 62.5 | 30.5 |
| Mortality (%) | 0.0 | 0.0 | 4.0 |
| Scorch (%) | 3.0* | 20.0* | 31.0 |

*Not significantly different from the prefire value at P = 0.05.

TABLE VI. FIRE EFFECTS ON DWARF MISTLETOE IN THINNED STANDS ON KELSEY BUTTE. REDUCTION WAS BASED ON THE PERCENT DECREASE FROM THE PREFIRE VALUE.

| Section: | 1E | 2A | 1B |
|---|---|---|---|
| Plots (n =): | 6 | 14 | 14 |
| | Percent reduction | | |
| Infected trees | 0 | 0 | 24 |
| Infected branches | 0 | 31 | 80 |
| Mistletoe plants | 0 | 27 | 88 |

Block 2A was on steeply sloping topography. It also had the smallest trees, averaging 15 cm dbh and 7.5 m in height, and tree size decreased with elevation on the butte, and ceanothus and manzanita increased in height relative to the trees, often reaching midcrown on some of the trees at the top of the slope. To avoid damaging crop trees, this plot was burned while it was sprinkling. Flame heights averaged only 51 cm, and fire spread at 55 cm per minute, the lowest intensity burn on the butte. Only one-third of the 31 plots were scorched at all (Table V).

Block 1B was located on moderately sloping terrain and resembled Block 2A most in its stand and fuel characteristics. Trees averaged 17 cm dbh and 8.5 cm height. This prescribed burn had the highest intensity and consumed the most fuel of the burns examined on Kelsey Butte. Although fuel moisture was comparable to the spring burns, scorch heights averaged 30 percent of the live crown length (Table V). Fire spread averaged 87 cm per minute. Basal area did not change significantly with burning for Kelsey Butte plots.

Block 1E was burned under fairly cool conditions and scorch was minimal. Block 2A was scorched in only one-third of its plots. The results shown here are for 14 out of 31 plots where there was noticeable fuel consumption. However, scorch was still irregular and insignificant. Block 1B, the fall burn, scorched one-third of the lower crown length and represented the only block where fire intensity was sufficient to cause significant pruning or effect on mistletoe.

The reduction of dwarf mistletoe in the thinned blocks on Kelsey Butte was closely related to crown scorch. Mortality contributed to the percent reduction of infected trees only on Block 1B (Tables V, VI, and VII). Block 1E had low mistletoe severity and low crown scorch resulting in no reduction of mistletoe. Block 2A had moderate mistletoe severity but an insignificant amount of scorch resulting in little sanitation over the entire block.

TABLE VII. FIRE EFFECTS ON DWARF MISTLETOE SEVERITY AND DISTORTION RATINGS FOR THINNED STANDS ON KELSEY BUTTE.

| Section:<br>Plots (n =): | 1E<br>6 | 2A<br>14 | 1B<br>14 |
|---|---|---|---|
| Hawksworth Rating | | | |
| Prefire | 1.3 | 2.5 | 3.2 |
| Postfire | 1.3* | 2.3* | 1.8 |
| Distortion | | | |
| Prefire | 8 | 19 | 40 |
| Postfire | 8* | 17* | 23 |

Table VI indicates some sanitation of infected branches and plants on those plots which were scorched in Block 2A. However, the dwarf mistletoe severity rating (Table VII) for the block was not significantly different from the prefire value. The low intensity fire on this section was intermediate between Block 1E and the low intensity plots on Pringle Butte. It had comparable scorch heights to the low intensity plots on Pringle Butte but had less mistletoe reduction (Tables V and VI) probably due to the variable nature of the burn.

Block 1B was an effective sanitizing burn. The stand burned with higher intensity and scorched a greater percentage of the crown, in a stand with more severe dwarf mistletoe infection. The amount of mortality was light and resulted from torching out of several infected trees (Tables V and VI). Scorch-pruning was more significant in reducing the proportion of infected trees from 45 percent to 35 percent after the fire. Scorch also significantly reduced the number of infected branches and mistletoe plants. Sanitation was more complete here than on the Pringle Butte high intensity plots because mistletoe rating was less severe and concentrations of mistletoe infections were higher in the lower branches (Table VII). The decrease in infection was comparable to the reduction on the high intensity plots on Pringle Butte, and brought mistletoe infections down to manageable levels. The mistletoe seed crop was also destroyed for the current year in this section because aerial mistletoe plants were scorched. However, it is not known how scorching mistletoe plants after pollination has occurred will affect fruitfulness the following year.

# DISCUSSION

Where fires were appropriate beneficial mistletoe reduction occurred. However, in both the thinned and unthinned areas, further reduction of mistletoe severity may be possible through reducing competition and increasing the vigor of the crop trees. This has been indicated in instances of manual treatment, and it is hoped that fire can duplicate these effects over a wider area and for less cost.

The long-term effects of prescribed burning on mistletoe plants, populations, and infected trees are areas of necessary research for different timber types, fire frequencies, and fire intensities. It was not possible to determine the burning characteristics of infected tissues in this study. However, it is known that infected branches have different bark characteristics in the area of infection than elsewhere. The presence of the mistletoe plant itself may alter the patterns of heat conduction to the cambium. Furthermore, it is necessary to relate fire behavior to the size and spatial distribution of infected biomass in the ground and crown fuels. The scorch of mistletoe plants in living branches suggests a higher sensitivity to the effects of heat and smoke than exhibited by the host. However, the period of recovery for scorched mistletoe plants is only speculative.

Not all stands are appropriate for burning to sanitize mistletoe. The results of this study indicate that fire may be used effectively to kill infected trees and to prune selected crop trees in pine stands. Low intensity fires, appropriate for prescribed understory burning, are generally insufficient to sanitize the dominant trees, including old-growth, whose crowns are above the mean scorch height. Fuel and weather conditions must also be appropriate to achieve desired levels of pruning and thinning.

## CONCLUSIONS

The results indicate that dwarf mistletoe can be partially sanitized from thinned and unthinned stands of ponderosa pine by prescribed understory burning. Sanitation is predictably more effective if burners actively discriminate against infected trees by shaping fires to thin and prune them. Scorch heights between 30 and 60 percent of the live crown length are required to significantly reduce the proportion of dwarf mistletoe in the crowns of crop trees. Mistletoe levels can thus be reduced from severe to tolerable levels if the crowns are not severely infected throughout their length.

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# GENERAL CONCLUSIONS

Interactions between fire and dwarf mistletoe in young stands of ponderosa pine indicate the need for special consideration of diseased stands in fuel and mistletoe management planning. Mistletoe infection was associated with altered size, distribution, amount, and vitality of fuels intercepted on the ground and in the crowns of infected trees. The basal diameters of infected branches are almost twice the size of healthy branches in diseased trees and one and one-half times the size of healthy branches in healthy trees. The increase in branch diameters is also indicated by increased fuel loadings in the 100 hour size class fuels both in the crowns and on the ground. Diseased branches brought to the ground by logging and natural pruning persist under the crowns of diseased trees increasing the proportion of fine fuels on the ground by 20 percent. Increased fuel loadings of fine fuels are more easily ignited and will promote fire spread.

Biomass in a diseased tree will be increasingly concentrated in infected branches and the distribution of crown biomass will be shifted downward with increasing mistletoe severity. Infected branches resist natural pruning and increase the amount of vital, aerial fuel close to the ground and hence to fire effects. Increasing proximity of diseased branches to the fire is expected to increase vulnerability to scorch, however, the thermal conductivity of infected branches relative to their healthy counterparts is not known. Diseased branches are more succulent, and vigorous; they have thicker bark and increased cambial area which should increase resistance to mortality from scorch.

In sample understory burns diseased trees were found to have higher levels of mortality and percentage of crown scorch than healthier trees. Precommercial stands of saplings and small poles were substantially thinned and pruned by fire effects resulting in significant reductions of dwarf mistletoe infected trees and branches. Severely infected plots were actively discriminated against in some cases by encouraging high levels of scorch through burning techniques. The mistletoe ratings were thus reduced from severe to moderate levels and almost 70 percent of the pre-fire infected biomass was killed. Moderately infected stands were reduced to light levels of infection with approximately half as much scorch and mortality. Young, dense stands which are bordering on unmanageable levels of disease may need prescriptions of two thirds crown scorch of an average crop tree. Moderate and light disease levels can be adequately brought within manageable levels by approximately one third of the lower crown length of crop trees (scorch-pruning). Note also that because of the increased basal distribution of biomass in diseased crowns the same height of scorch will remove proportionately more crown length and volume in diseased than in healthy trees.

Thinning had already done much to reduce the amount of mistletoe in sample stands of pole sized timber. Here spacing, and hence mortality, were more critical and disease reduction occurred primarily by scorch-pruning rather than by killing infected understory trees. The degree of sanitation was directly proportional to the height of crown scorch. Three percent scorch-pruning of crown length was inadequate to reduce mistletoe in lightly infected stands, nor did 20 percent crown scorch significantly reduce the mistletoe rating in moderately infected stands although one third of the mistletoe infected branches were killed. However, 31 percent of scorch in the crowns of severely diseased stands killed 80 percent of the infected branches and reduced the mistletoe rating to a moderate level. In the latter instance 24 percent of the infected trees were killed which also influenced mistletoe reduction. In general, in both thinned and unthinned pre-commercial stands a scorch height of at least 30 percent of the lower crown length will probably be required to keep mistletoe within manageable levels. More investigation is necessary under different stand conditions with variable levels of mistletoe and periodic burning. Flammability of diseased fuel under more controlled conditions also needs to be investigated.

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