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Forest Ecology and Management 255 (2008) 2907–2915

Forest Ecology and Management

www.elsevier.com/locate/foreco

Full length article

Thinning and prescribed fire effects on dwarf mistletoe severity in an eastern Cascade Range dry forest, Washington

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Received 30 November 2007; received in revised form 17 January 2008; accepted 22 January 2008

Abstract

Forest thinning and prescribed fire practices are widely used, either separately or in combination, to address tree stocking, species composition, and wildland fire concerns in western US mixed conifer forests. We examined the effects of these fuel treatments alone and combined on dwarf mistletoe infection severity immediately after treatment and for the following 100 years. Thinning, burning, thin + burn, and control treatments were applied to 10 ha units; each treatment was replicated three times. Dwarf mistletoe was found in ponderosa pine and/or Douglas-fir in all units prior to treatment. Stand infection severity was low to moderate, and severely infected trees were the largest in the overstory. Thinning produced the greatest reductions in tree stocking and mistletoe severity. Burning reduced stocking somewhat less because spring burns were relatively cool with spotty fuel consumption and mortality. Burning effects on vegetation were enhanced when combined with thinning; thin + burn treatments also reduced mistletoe severity in all size classes. Stand growth simulations using the Forest Vegetation Simulator (FVS) showed a trend of reduced mistletoe spread and intensification over time for all active treatments. When thinned and unthinned treatments were compared, thinning reduced infected basal area and treatment effects were obvious, beginning in the second decade. The same was true with burned and unburned treatments. Treatment effects on infected tree density were similar to infected basal area; however, treatment effects diminished after 20 years, suggesting a re-treatment interval for dwarf mistletoe.

Keywords: Dwarf mistletoe; Dry forest; Prescribed burning; Thinning; Fire and Fire Surrogate

1. Introduction

Dwarf mistletoes (Santales/Viscaceae/*Arceuthobium* spp.) are chlorophyllous, obligately parasitic seed plants native to both wet and dry coniferous forest habitats throughout North America (Geils et al., 2002). Due to their wide distribution in the West (Bolsinger, 1978), dwarf mistletoes are probably responsible for more tree growth and mortality losses each year than all other forest pathogens combined. These long-lived pathogens infect host trees by ballistically discharged seeds (Strand and Roth, 1976), and feed directly from the water and mineral supply of a host tree via an endophytic root system (Alosi and Calvin, 1985; Calvin and Wilson, 1996; Scharpf and Parameter, 1967). Long-standing infections result in growth reductions (Baranyay and Safranyik, 1970; Geils et al., 2002; Hawksworth and Wiens, 1996), depressed tree vigor, and tree mortality (Hadfield and Russell, 1978), either directly caused, or in concert with other pathogens (Filip, 1984; Filip et al., 1993). Infected trees develop ‘‘witches’ brooms’’ (Hawksworth, 1977; Hawksworth and Wiens, 1972), which are the areas of prolific branch growth and differentiation. Brooms provide essential habitat for over 40 bird and mammal species, and food for insects during periods between flowering events (Geils et al., 2002; Hawksworth and Geils, 1996).

Distribution of most dwarf mistletoes has likely increased in western North America over the 20th-century due to widespread fire suppression and selection cutting (Bolsinger, 1978; Hessburg et al., 1999, 2000). In contrast, pre-management era fires likely reduced historical dwarf mistletoe infestations; directly, by selectively removing heavily infested trees and branches via torching, and indirectly, by simplifying forest structure and increasing average inter-tree spacing (Hessburg et al., 1994). Low density and simply layered stands, maintained by surface fire dominated regimes, slowed local and lateral spread of dwarf mistletoe, however, bird vectoring likely continued. Moderately dense multi-layered stands, on the

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2008.01.066

other hand, tended to increase diseases spread by providing open areas in the vertical canopy profile for seed dispersal, and receptive understory hosts for seed interception.

Stands with relatively severe infections can increase fuel loadings, and thereby, crown fire potential, by adding both canopy and surface fuels (Koonce and Roth, 1985; Godfree, 2000). For example, in ponderosa pine forests of northern Arizona, Hoffman et al. (2007) found that moderate to severely infested stands had higher total fuel loadings than light and un-infested stands, which in turn increased likelihood of crown fire initiation and spread.

Contemporary treatment to manage dwarf mistletoe severity is generally thinning to reduce stand and tree mistletoe rating and related long-term growth and mortality impacts to residual trees. Where infection severity renders stand conditions unmanageable (thinning alone produces inadequate height or diameter growth response), more aggressive stand-replacing harvests may be called for (Gill and Hawksworth, 1954; Hadfield and Russell, 1978; Hawksworth, 1978).

Few studies report on effects of fuels reduction treatments on dwarf mistletoe severity (Alexander and Hawksworth, 1975; Conklin and Armstrong, 2001; Van der Kamp and Hawksworth, 1985). In prescribed fire trials in southwestern ponderosa pine, Conklin and Armstrong (2001) showed that trees with moderate and high infection severity were more often killed by fire than trees with low infection severity; however, effects on mistletoe severity were significant only in the moderately infested stands, which corroborated the results of Koonce and Roth (1980) and Harrington and Hawksworth (1990).

In the current study, combinations of thinning and burning treatments were applied to dry mixed conifer forests of eastern Washington State, which are typical of fuels reduction treatments used throughout mixed conifer forests of the western US. Elimination of mistletoe was not the primary intent of treatments. The objectives of this study were to (1) quantify pre- and post-treatment dwarf mistletoe infection severity in treatment units of the Fire and Fire Surrogate (FFS) study's Mission Creek site, (2) quantify treatment effectiveness at reducing stand-level mistletoe infection severity and (3) to compare treatment effects on future stand growth and yield, and dwarf mistletoe infection severity using the Forest Vegetation Simulator (FVS).

2. Methods

2.1. Study area

The study was conducted in the eastern Cascade Range of Washington State within the confines of the Okanogan-Wenatchee National Forest (Fig. 1). The Mission Creek study site (47°25′42″N, 120°32′42″W) was one of the 12 in the FFS project (http://frames.nbii.gov/ffs); a long-term study to assess the effectiveness and ecological impacts of surrogate treatments such as thinning, that are used instead of or in combination with fire.

Dry forests of the study area are dominated by ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) in the overstory, with generally mixed Douglas-fir, ponderosa pine, and occasionally grand fir (*Abies grandis*) understories. Plant associations are among those on the dry end of the Douglas-fir and grand fir series (Lillybridge et al., 1995). Climate of the area is continental but with rain shadow effects produced by the Cascade Range. Average annual precipitation is about 56 cm, mostly occurring as snow during the winter months. Soils of the immediate study area are stony, sandy loams and stand slope averages vary from 30 to 50% (Zabowski et al., in press).

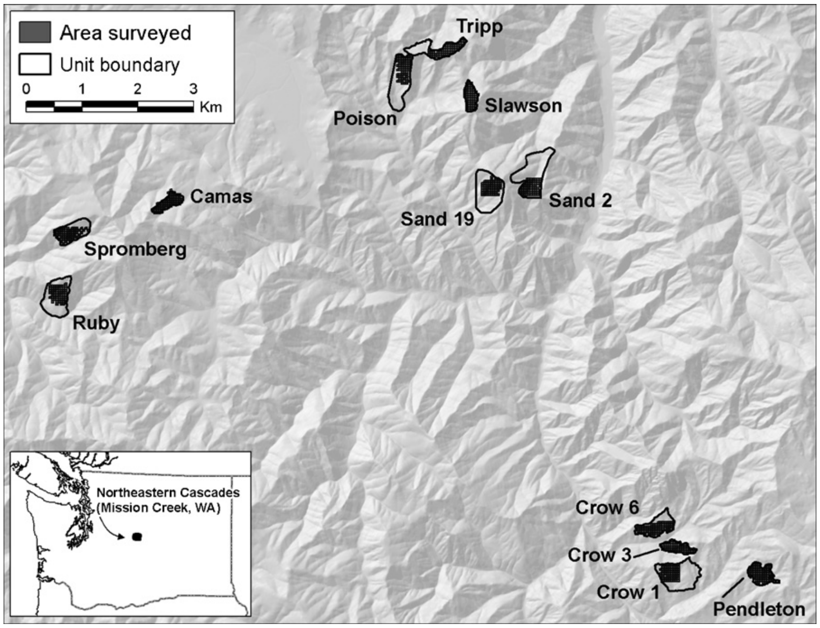

Fig. 1. Vicinity map of the Mission Creek Fire and Fire Surrogate Study Area showing experimental unit boundaries and sampled areas.

2.2. Treatments

Twelve treatment units, 10 ha in size were chosen for the study (Fig. 1). The treatments were: (1) commercial thinning alone, (2) prescribed fire alone, (3) commercial thinning followed by prescribed fire, and (4) untreated control. By the study design, treatment assignment was random, producing three replicates of each treatment, with the exception that four units could not be considered for the prescribed fire treatments due to road access limitations. Treatment units were relatively homogeneous stands occurring on southerly aspects, with average slopes <40%, and <10% rock or non-forest vegetation cover. Objectives common to all treatment methods were to restore low-density dry forest stand structure, reduce ladder and surface fuels, and reduce the risks of bark beetle attack and high-severity fire. The overarching objective of the national FFS study was to yield post-treatment stands with an 80% co-dominant and dominant tree survival rate under an 80th percentile fire weather scenario.

Thinning treatments were designed to reduce stand density and favor drought and fire-tolerant species (i.e., the largest ponderosa pine and/or Douglas-fir). Residual overstory densities of dominant and co-dominant trees were targeted to fall within the estimated historical overstory density for the area (ca. 50 trees ha^{-1}, Harrod et al., 1999). Stands were generally low thinned leaving the largest and most vigorous trees at an irregular spacing. Thinning was accomplished with chainsaw felling during the winters of 2002–2003, slash was left in place, and logs were helicopter yarded to external landings.

Prescribed fire treatments were conducted on only four of the six units in the spring of 2004 and, due to unsuitable burn conditions, two units were left unburned in 2004. This resulted in an unbalanced design. Ignition was by hand and helicopter lighting. In 2004, flame lengths ranged from 0.2 to 1.0 m, and burns were patchy (23–51% area blackened) with the spring burn conditions (Agee and Lolley, 2006).

2.3. Data collection

For each treatment unit, a 40 m × 40 m grid was overlaid atop high-resolution (0.2 m ground resolution) color digital orthophotographs to identify locations of sample points. Within each treatment unit, 32 basal area factor (BAF) 20, variable-radius prism plots (6 cm minimum DBH) were situated on every other grid cell (random start) to develop a stand table and estimate dwarf mistletoe incidence and severity. Tree height (m), diameter at breast height (DBH, cm), tree species, status (dead, symptomatic, and nonsymptomatic), damaging agent(s), live crown ratio (LCR), radial growth (from increment cores, last 10 years), and dwarf mistletoe rating (DMR, Hawksworth, 1977) data were recorded on the first tree of each species, at each point. The recorded DMR only reflected mistletoe infections that are visibly indicated by signs and symptoms of this disease; latent infections (those lacking visible signs and symptoms) were not considered. With the exception of the height and radial growth measurements, the same data were collected on all other trees occurring in the variable radius plots. Data were collected before (2000) and after (2004) treatments were implemented. Protocols for data collection were consistent for the pre- and post-treatment survey; however, the grid system was shifted to alternating grid cells to reduce temporal autocorrelation in the analysis.

2.4. Analyses

Differences among treatments in pre-treatment tree density (TPH), basal area (BA), and dwarf mistletoe severity were analyzed using two-way analysis of variance (ANOVA) for completely randomized designs with subsampling. To complete this analysis, the general linear model (PROC GLM, SAS, 2004) was used with appropriate main plot error terms and Type III sums of squares. To detect pretreatment differences in tree growth and stature by mistletoe severity, we pooled trees across all treatment units, and using a nonparametric, rank-ordered abundance test, the Mann–Whitney *U*-test, compared radial growth, diameter (DBH), age (breast height), and LCR at no (DMR = 0), low- (DMR = 1–3), and high- (DMR = 4–6) severity levels. We used a paired *t*-test to analyze differences in initial infection severity on ponderosa pine and Douglas-fir over all treatment units.

Treatment effects were analyzed using mixed effects ANOVA for completely randomized designs with subsampling (PROC MIXED; SAS, 2004). A mixed model approach was chosen over traditional ANOVA because it enabled partitioning of variance both within and among treatment units, and increased power to detect significance. Treatment effects analysis was repeated with traditional ANOVA methods with no important differences in results. Mixed model fixed effects included thinning and burning treatments and their interaction, and a time variable to identify that pre- and post-treatment samples were taken from non-repeated randomized grids. Random effects included the treatment unit and time × unit interaction. The "variance components" covariance structure was used for all models based on comparisons of AIC statistics with other common structures, and restricted maximum likelihood (REML) was used due to its utility in dealing with unbalanced designs (Searle et al., 1992). Dependent variables included total TPH, total tree BA, infected TPH, infected BA, average DMR, and average dwarf mistletoe rating of infected trees (DMI). For all parametric analyses, model assumptions of equal variance and normality were evaluated using histograms, *Q*–*Q* normal plots and other diagnostics; transformations were applied to dependent variables as needed to meet model assumptions.

We accepted $P \leq 0.10$ as the observed probability level for Type I error in hypothesis tests. Although less conservative than $P \leq 0.05$, we considered $\alpha = 0.10$ to be an acceptable chance of Type I error for field studies, and well within the bounds of convention (Zar, 1999). A significant difference is implied where a difference among means is reported; but, we reported exact *P*-values in the text to allow readers to assess the probability of error relative to their standard of significance (Zar, 1999).

To test for outliers, Grubbs (1969) test was applied to all 12 treatment units comparing pre- and post-treatment mistletoe-infected BA and TPH. Treatment unit Sand 19 was excluded as an outlier from subsequent analysis ($P = 0.05$, BA test, Sand 19 Z-statistic = 2.57, critical Z for sample of 12 = 2.41; TPH test, Sand 19 Z-statistic = 2.71, critical Z for sample of 12 = 2.41). The final design submitted to all further analyses was controls ($n = 3$), thin-only ($n = 4$), burn-only ($n = 2$), and thin + burn ($n = 2$). All analyses were conducted using SAS version 9.1.2 and SPSS version 10 (SAS, 2004; SPSS, 1999).

2.5. Predicting future infection severity

Immediately after treatment, we anticipated that treatment effects might be insignificant due to (1) low mistletoe infection levels, (2) unreleased latent infections immediately after thinning (Tinnin et al., 1999), (3) relatively low analysis power, and (4) insufficient time since treatment. To determine whether longer-term treatment effects were likely, we ran stand growth simulations in the FVS (Dixon, 2002), and reported conditions at decadal intervals. The FVS is an individual-tree, distance-independent growth and yield model. It has been calibrated for specific geographic areas (variants) of the US; we used the Eastern Cascades (EC) variant for our simulations. FVS can simulate a wide range of silvicultural treatments for most major forest tree species, forest types, and stand conditions. The stand is the population unit used to model individual tree interactions. Stand table data coming from forest inventories, stand examinations, or similar surveys can be used to describe the initial stand conditions. Input files to FVS include ‘‘keywords’’ the user can manipulate to simulate different management scenarios. In our simulations, we grew the pre- and post treatment stands for 100 years without harvest entry (empirical yields). In addition, there are extensions to the FVS variants that simulate the influence of other agents upon tree growth, such as insects and diseases. We used the Interim Dwarf Mistletoe Impact Modeling (IDMIM) system (Hawksworth et al., 1992) to simulate spread and intensification of mistletoes in study stands (treatment units).

3. Results

3.1. Pretreatment severity

Across all treatment units, dwarf mistletoe was present in about one-third of the sampled grid points at the start of the experiment. Infection severity was highest in thinning units (thin-only and thin + burn), where mistletoe was found in 60% of the grid points (ANOVA, $P = 0.097$). Stand infection severity was low to moderate, with DMR averaging <3 on most sample plots. Areas of high (DMR ≥ 4) mistletoe infection were observed on $<10\%$ of treatment units. Average DMI was similarly low, ranging from 1.0 to 3.1.

Dwarf mistletoe was found on both Douglas-fir and ponderosa pine, and across all treatment units, approximately 3.6 $m^2\ ha^{-1}$ (13.8%) of the BA was infected. Of the 1918 trees measured prior to treatments, 1648 (85.9%) were uninfected, 210 (10.9%) displayed low to moderate infection severity (DMR = 1–3), and 60 (3.1%) were severely infected (DMR = 4–6). Pre-treatment differences in infected BA and infected TPH among treatments were insignificant (ANOVA, $P > 0.115$). Across the study area, Douglas-fir accounted for 46.4% of all trees and ponderosa pine represented 48.8%; grand fir accounted for the remainder and occurred as a minor component, especially at higher elevations. Ponderosa pine displayed a higher infection rate compared to Douglas-fir, with mistletoe occurring on 18.9% of pine BA compared to $<10\%$ of Douglas-fir (paired t-test; $P = 0.035$, Fig. 2).

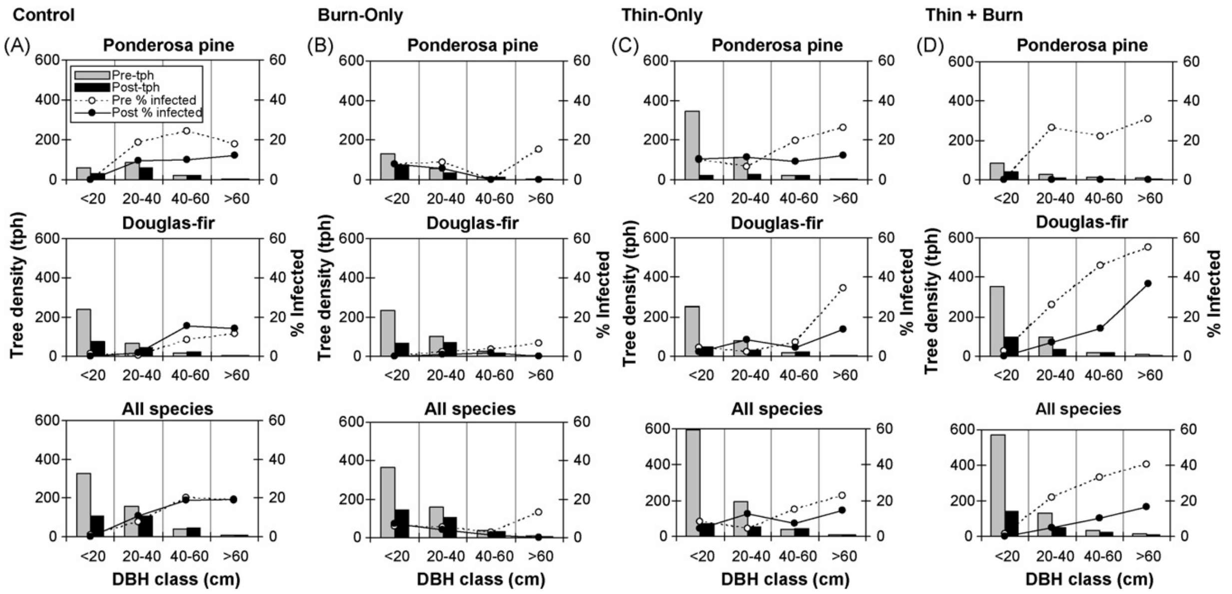

Fig. 2. Diameter distribution and percentage of dwarf mistletoe infected trees per hectare (tph) for tree species sampled prior to (pre) and immediately following (post) control (A), burn-only (B), thin-only (C), and thin + burn (D) treatments of the Fire and Fire Surrogate project at the Mission Creek site. Pre- and post-treatment samples were equal sized and taken from independent randomized grids.

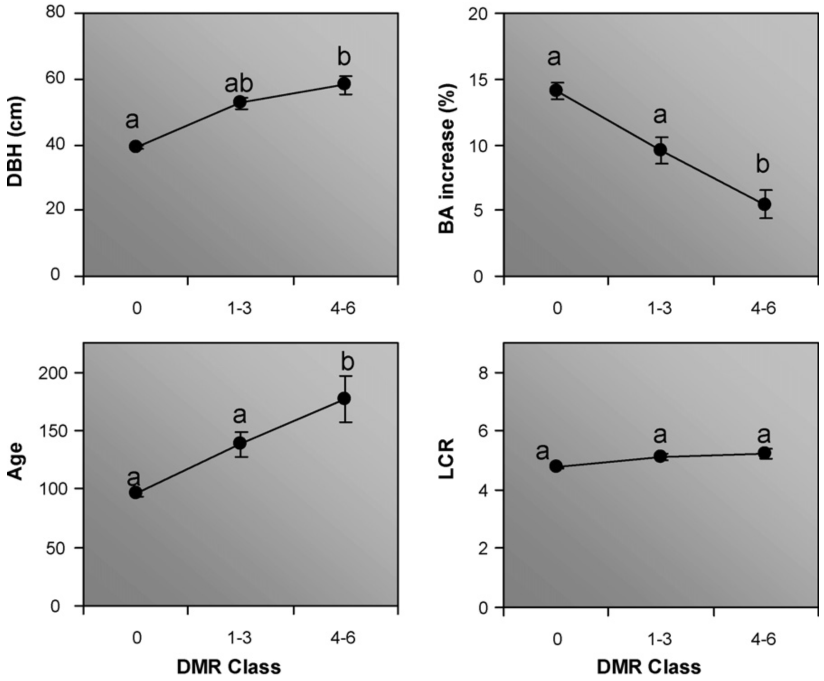

Fig. 3. Average diameter at breast height (DBH), 10-year basal area growth (%BA increase), tree age, and live crown ratio (LCR) by dwarf mistletoe rating (DMR) class for all pre-treatment trees of the Fire and Fire Surrogate project at the Mission Creek site. Graphed points with differing lower case letters are significantly different (Mann–Whitney *U*-test, $P \leq 0.015$).

Severely infected trees ($DMR > 4$) were on average >150% larger than uninfected trees (Mann–Whitney *U*-test; $P = 0.001$, Fig. 3, DBH), indicating that infections were more common and severe in large diameter trees. Four percent of the BA in trees <20 cm DBH was infected with dwarf mistletoe compared with more than 20% of the BA for trees >60 cm. This trend was consistent for both Douglas-fir and ponderosa pine; however, infection rates in ponderosa pine were generally higher for all but the >60 cm size class. The distribution of ages was also disproportionate among mistletoe infection classes; the most severe infections tended to occur in old trees (Mann–Whitney *U*-test, DMR = 0 vs. DMR = 4–6, $P = 0.002$; DMR = 1–3 vs. DMR = 4–6, $P = 0.015$, Fig. 3, tree age). Trees with high DMR also exhibited slower radial growth rates over the previous 10-year period than trees with low ratings. Uninfected trees exhibited a 14.6% increase in BA over the last decade [(BA year 2000 − BA year 1990)/BA year 1990 × 100], compared to a 5.5% increase for trees with severe infections (Mann–Whitney *U*-test, $P = 0.003$, Fig. 3, BA increase). No differences in LCR were significant among infected and uninfected trees (Fig. 3, LCR).

3.2. Treatment effects on dwarf mistletoe

Thinning and prescribed fire treatments produced apparent changes in total TPH, mistletoe infected TPH, total BA, and infected BA, in all treatments (Fig. 4), but no reduction was significant. Change in average DMR was also negligible ($P > 0.205$). However, thinning treatments (thin-only and thin + burn) yielded a significant reduction in total density. For example, thinning reduced total density (ANOVA, mixed model, $P = 0.0474$); but burning (burn-only and thin + burn) did not (ANOVA, Mixed Model, $P = 0.201$, Figs. 2 and 4). There was an apparent decline in total BA (−38.2%) among active treatment units, with thin-only and thin + burn treatments removing >40%, and burn-only removing 25%, but treatment effects were not significant (ANOVA, Mixed Model; thinning, $P = 0.131$; burning, $P = 0.2218$). Most tree density reduction occurred in the <20 cm and 20–40 cm DBH classes, with the largest declines occurring on thin-only and thin + burn treatment units (Fig. 2).

Apparent declines in dwarf mistletoe infection severity were in evidence under all treatment combinations, but again no difference was significant (ANOVA, Mixed model, $P > 0.141$, Fig. 2). The effect of the thin-only treatment on total tree density was disproportionate to its effects on infected tree density (i.e., there was evidence of some bias for retaining mistletoe infected trees). Burn-only treatments proportionately reduced total and infected tree density. The thin + burn treatment removed a higher proportion of infected trees than total trees (89% of infected trees and 61% of all trees).

3.3. Future infection severity

Results from FVS simulations indicated that treatments may have long-term effects on reducing dwarf mistletoe severity. Lasting treatment effects were most obvious with the thin + burn treatment, where infected BA never exceeded 10 $m^2 ha^{-1}$ for the first century after treatment, despite having the highest initial infection level (Fig. 5A). The thin-only treatment also yielded a

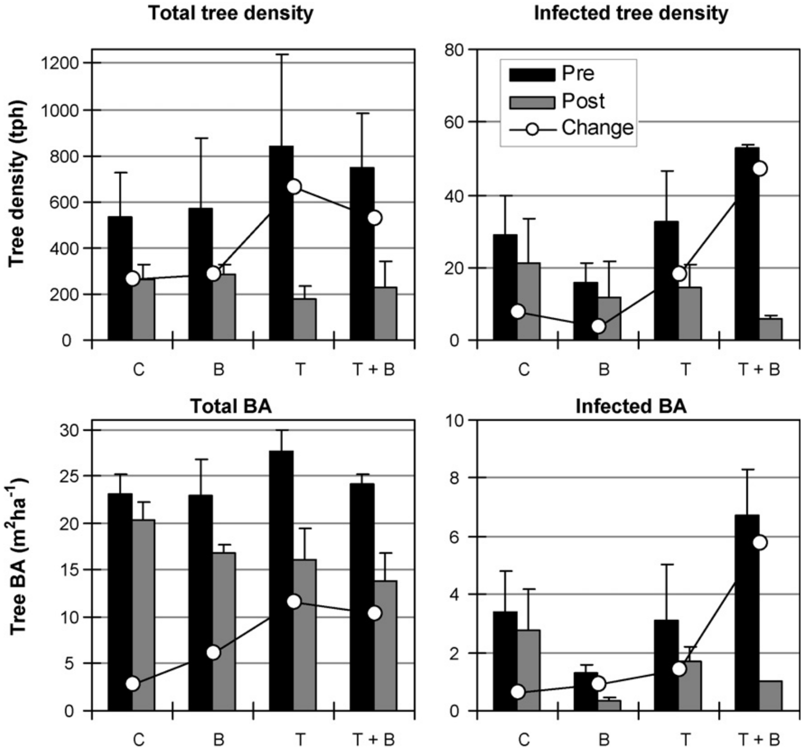

Fig. 4. Change in total tree density, mistletoe infected tree density, total tree BA and mistletoe infected BA from pre- to post-treatment of the Fire and Fire Surrogate project at the Mission Creek site. Symbols are C, control; B, burn-only, T, thin-only; T + B, thin + burn. No differences were significant immediately after treatment. ''Change'' reflects differencing of the pre- and post-treatment conditions expressed in the referenced units of measure.

persistent treatment effect on infected BA beginning in the second decade (Wilcoxon's signed ranks paired test, untreated vs. treated, $P \leq 0.068$, Fig. 5A); however, predicted future infection levels were highest in these units, perhaps due to the aforementioned bias in retaining infected trees. The burn-only treatment, despite having a minimal effect on infected BA, had a larger effect on future dwarf mistletoe severity compared to the thin-only treatment. This may have been partially due to the fact that burn-only treatment units had low initial infection levels, and burn treatment primarily influenced small seedling, sapling, and pole-sized trees with thin bark.

When thinned (thin-only and thin + burn) and unthinned (control and burn-only) treatments were compared, thinning yielded a persistent treatment effect on infected BA beginning in the second decade (Wilcoxon's signed ranks paired test, untreated vs. treated, $P \leq 0.028$, Fig. 5B). When burned (burn-only and thin + burn) and unburned (control and thin-only) treatments were compared, burning yielded a persistent treatment effect on infected BA beginning right after treatment and continuing for 100 years (Wilcoxon's signed ranks paired test, untreated vs. treated, $P \leq 0.068$, Fig. 5B). Treatment effects on infected tree density were similar to infected BA (Fig. 5C and D); however, treatment effects diminished after about 20 years.

4. Discussion

Dwarf mistletoe infections occurred in ponderosa pine and/or Douglas-fir in all units prior to treatment. Stand infection severity was generally low to moderate, and severely infected trees were the largest and oldest overstory trees. Thinning treatments produced the most apparent reductions in tree stocking and mistletoe severity. The burn-only treatment reduced stocking and basal area somewhat less; spring burns were relatively cool with spotty fuel consumption and mortality. Prescribed fire effects on vegetation were enhanced when combined with thinning; thin + burn treatments led to the largest declines in dwarf mistletoe in all size classes. All thinning and prescribed fire treatments reduced dwarf mistletoe severity; however, no differences were significant immediately after treatment.

It is noteworthy that most treatments did not enhance mistletoe severity as in the case of high-grade logging or selection cutting even though mistletoe control was not the focus of treatments. They were, instead, mostly mistletoe neutral or negative. By consistently discriminating against the most severe mistletoe infections during tree marking and removal, silvicultural prescriptions could be readily adapted to meet fuel reduction and density objectives while reducing mistletoe severity.

Mistletoe control was not the primary treatment objective in this study; hence, results should be taken in the context of fuels reduction. Harrod et al. (2007) found that thinning in these same units reduced tree stocking, canopy bulk density and canopy fuels by >50%, mostly in the small (<20 cm DBH) and medium (20–40 cm DBH) size classes; similar reductions were reported for the thin-only and thin + burn treatments. The

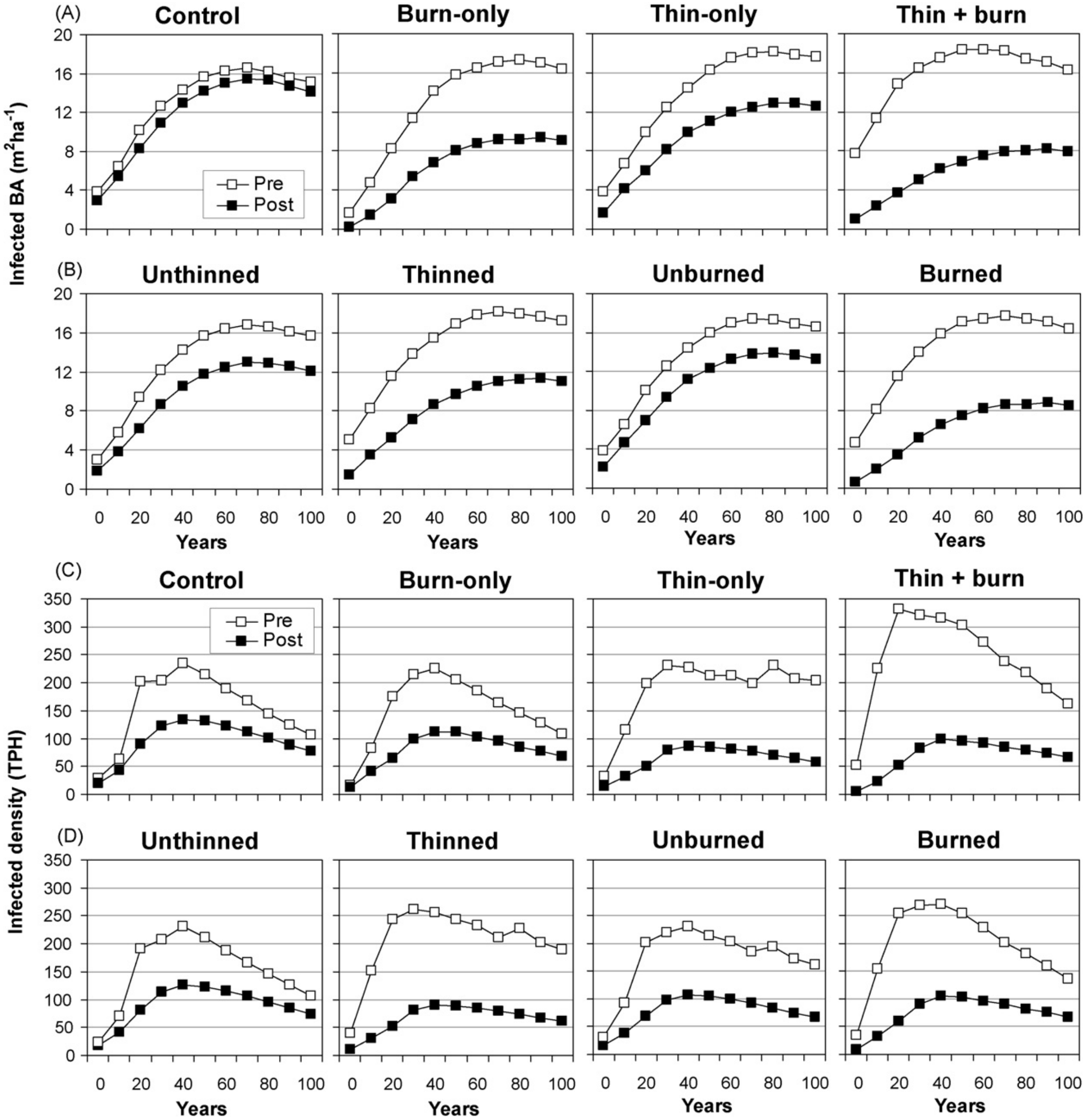

Fig. 5. Predicted future decadal levels of dwarf mistletoe infected basal area and trees per hectare as predicted by the FVS for the 100 years immediately following treatment in the Fire and Fire Surrogate project at the Mission Creek site. Simulations were run for each treatment unit using pre-treatment (open symbols) and post-treatment (closed symbols) stand inventories. ‘‘Thinned’’, ‘‘Unthinned’’, ‘‘Burned’’, and ‘‘Unburned’’ indicate pooling of the thin and thin + burn, control and burn, burn and thin + burn, control and thin treatment data for FVS simulation, respectively.

burn-only treatment, however, had little effect on stocking or canopy fuels and likely had a null effect on crown fire potential in these forests.

Agee and Lolley (2006) similarly found that spring burning treatments (burn-only and thin + burn) in these same units had a minimal effect on surface fuels and were ineffective in altering stand structure or reducing potential surface wildfire behavior. They suggested that the spring-ignited fires did not meet fuel management objectives because fire spread was poor and unevenly distributed. They noted that while dead fuel moistures were adequate to meet the intent of the burn prescription, early greening of herbs and grasses retarded fire spread. They found that only two of four ignited fires exhibited burn coverage >50%; in effect, >50% of the scheduled burn area remained unburned. Further, Agee and Lolley (2006) found that thinning alone, while effectively reducing stocking and canopy fuels, led to increase in surface fuel loading, which in turn increased future torching potential in these stands. Taken together, only the thin + burn treatment satisfied the combined restoration objectives of (1) reducing tree stocking, (2) reducing canopy and surface fuel levels, and (3) controlling mistletoe populations. These results suggest focusing expanded cooperative research and management effort on customizing and optimizing thin + burn treatments to these combined ends.

The lack of canopy scorching afforded by cool spring burns of this study is not a trivial matter when the effects of frequently occurring historical fires on mistletoe infection severity are considered. Historical fires typically occurred in the dry summer season when fuels were well cured. The energy release associated with summer fires, even with surface fire dominated regimes, would have caused greater canopy scorch than was realized in this study, which would have further discriminated against mistletoe infection severity by elevating live crown base heights, eliminating large, heat-trapping, mistletoe brooms from low and middle crown positions, and torching the most severely infected trees and tree groups (Conklin and Armstrong, 2001; Hessburg et al., 1994; Hoffman et al., 2007; Koonce and Roth, 1985).

4.1. Future infection severity

Growth and yield simulations using the FVS showed a trend of reduced mistletoe spread and intensification over time for all active treatments. When treatment units were projected into the future and compared to the same units left untreated (Fig. 5), all active treatments yielded a persistent effect on infected BA beginning in the second decade. Similar results were found for infected tree density; however, treatment effects diminished after about 20 years, suggesting a re-treatment interval for dwarf mistletoe. The pronounced effect of the burn-only treatment (Fig. 5) may be partially due to the fact that burn-only treatment units had low initial infection levels, and the burn treatment primarily targeted small seedling, sapling, and pole-sized trees with thin bark. However, this does not imply that burning alone cannot be used for mistletoe control. For instance, Conklin and Armstrong (2001) found that 3–8 years following prescribed burns in ponderosa pine forests in the Southwest, stand-level DMR scores declined by 0.3–1.6% and the proportion of infected trees reduced by 5–18%. The authors concluded that well-implemented burns could cause a significant retrogression in mistletoe severity. Further, prescribed burning may be necessary in stands with high-severity mistletoe infections where surface fuel levels are generally higher due to the deposition of resinous brooms, dead branches and snags (Conklin and Armstrong, 2001; Koonce and Roth, 1985).

The mistletoe at Mission Creek and much of that found throughout the West is an enduring residue of historical selection cutting (Hessburg et al., 1994, 2000). In some stands, the worst current infections are relegated to the larger overstory size classes, in trees of early seral species that managers would otherwise wish to retain for future forest structure; 20th-century logging practices focused on removal of the largest and highest quality trees. However, because these remaining large trees can be the most damaging mistletoe seed source for spread and intensification, foresters are faced with a challenge: if they remove infested overstory trees, even fewer large trees remain; but if they retain them, the future forest may become severely infected by dwarf mistletoe and stand conditions could be unmanageable due to mistletoe alone. In cases where large old mistletoe-infected overstory trees are important to certain wildlife species or are important for other reasons, they may be retained in the overstory with little consequence to the understory if certain concerns can be addressed. For example, dwarf mistletoes are relatively host-specialized, meaning that the mistletoe species that infects Douglas-fir will not spread to ponderosa pine or western larch (*Larix occidentalis*). In cases where a mistletoe-infected overstory of Douglas-fir is to be retained, ponderosa pine and western larch may be planted in the understory, because they are immune to the Douglas-fir dwarf mistletoe. Since ponderosa pine and western larch are quite shade-intolerant, an overstory stocking should be retained that does not inhibit vigorous pine or larch growth and differentiation by creating too much shade. In future entries, if Douglas-fir in the understory is discriminated against at each thinning entry, the future overstory will be comprised of disease-free ponderosa pine and/or western larch.

The Joint Fire Sciences Program plan for the FFS national site network is to repeat burning treatments every 5–10 years, thinning treatments every 20–30 years, and re-measure key response variables. This will allow quantification of the longer-term effects of initial treatments, effects of maintenance treatments, and of the efficacy of prescribed fire and thinning in promoting forest health of dry mixed conifer forests. For instance, latent mistletoe infections often take several years to fully respond to a release treatment, and future monitoring of treatment effects on mistletoe severity is warranted.

Acknowledgements

This research was conducted through a grant from the National Fire and Fire Surrogate (FFS) Program of the United States Joint Fire Sciences Program. This is Contribution Number 176 of the FFS Program. We appreciated field assistance provided by Jim Huinker, Brock Applegate, Eric Pentico, Anne Conway, Emily Drew, Kevin James, and James Begley. John Lehmkuhl, Jim Agee, and Richy Harrod provided reviews of an earlier draft, and we appreciate the anonymous reviews of the referees. We are grateful to the Okanogan-Wenatchee National Forests for implementing the treatments.

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