Restoring East-Side Ponderosa Pine Ecosystems at the Blacks Mountain Experimental Forest: A Case Study

Jianwei Zhang and Martin W. Ritchie

ABSTRACT

The ecological research project of interior ponderosa pine forests at the Blacks Mountain Experimental Forest in northeastern California was initiated by an interdisciplinary team of scientists in the early 1990s. The objectives of this study were to determine the effects of stand structure, and prescribed fire on vegetation growth, resilience, and sustainability of ponderosa pine ecosystems. Two stand structures were created with mechanical thinning on 12 units of about 100 hectares each. The low structural diversity (LoD) treatment has an even spaced, continuous canopy with few snags and few large canopy gaps. In contrast, the high structural diversity (HiD) includes many large, old trees with multiple canopy layers, abundant large diameter snags, many small canopy gaps, and some dense clumps of smaller trees. Each structural treatment was randomly assigned in each of three blocks. Each combination (unit) was split into two halves and prescribed fire was applied to one of the split plots after the completion of thinning. Because of the complexity of treatments and large experimental units, thinning and prescribed burns took 5 years to complete. Accordingly, our first post-treatment measurements were staged one year after implementation of prescribed fire. The second post-treatment measurements were completed five years after the initial measurement. In the short term, we found that (1) tree growth and understory woody plant cover significantly responded to structural diversity, but not prescribed fire; (i) the HiD plots carried much more basal area and stems than low structural diversity (LoD) plots, (ii) both individual-tree and stand-level growth increment was higher in the LoD plots than in the HiD plots, and (iii) understory woody plant species grew back in five years with higher percentage cover in the LoD than in the HiD, (2) prescribed fire effect was significant for dead woody materials on the forest floor and bark beetle colonization; (i) debris was reduced significantly more with prescribed fire and (ii) bark beetles tended to attack trees weakened by the prescribed fire, (3) by comparing adjacent untreated stands, our HiD treatment appeared to improve health of the largest trees (DBH > 60 cm) in the stand, and (4) no significant interaction was found between structural diversity and prescribed fire. These results suggest that ponderosa pine forests can be treated to enhance stand growth and health without sacrificing understory vegetation diversity and stand productivity in the short-term.

Keywords: interdisciplinary research, ponderosa pine forest, thinning, prescribed fire, stand dynamics, understory shrubs

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INTRODUCTION

In recent decades the Forest Service has applied a multiple-use philosophy in managing the national forests and grasslands (Wilkinson and Anderson 1987). This has not only focused on the production of valuable commodities such as wood, fiber, food, water, and minerals for human use, but also emphasized recreational, spiritual, aesthetic, and educational experiences on the public lands (Kessler et al 1992). Effective management can be helped by interdisciplinary research that addresses multiple factors (Oliver 2000).

Recommendations from the National Research Council (1990) and the Forest Service Strategic Plan for Research (1990) led the Pacific Southwest Research Station to establish an interdisciplinary team to consider research needs in interior pine forests. The team began planning a large-scale ecological research project at Blacks Mountain Experimental Forest in northeastern California in 1991. Experimental design, National Environmental Policy Act (EPA) documentation, and timber sale preparation took some five years; treatments were initiated in 1996. Treatment installation was completed in October of 2000 when the prescribed burning treatment was applied to the last block.

The objectives of this long-term study are to increase our understanding of the effects of forest structural complexity and prescribed fire on health and vigor of an interior ponderosa pine ecosystem and to determine how these ecosystems can be managed for sustained resource values (Oliver 2000; Oliver and Powers 1998). Blacks Mountain Experimental Forest was chosen for this project because of the existing forest conditions with a representative late seral structure still extant. Designated in 1934 as an Experimental Forest, it is one of the few forests in the United States with more than 50 years of records on forest structure. The forest has an extensive, well-designed road and compartment system.

In this report, we will review some short-term results from this study from the initial 5-year post-treatment period. These results are primarily from manuscripts submitted to a special issue of Canadian Journal of Forest Research entitled "Interdisciplinary Research on Interior Pine Forests at Blacks Mountain Experimental Forest" submitted for publication in 2008. We appreciate all authors who allowed us to use their unpublished data.

SITE DESCRIPTION

Blacks Mountain Experimental Forest is located approximately 35 km northeast of Mount Lassen in northeastern California (40°40' N latitude, 121°10' W longitude). The forest occupies 3,715 ha on the Lassen National Forest; elevational range is between 1,700 m and 2,100 m. Soils are Typic Argixerolls, 1-3 m deep over basalt with mesic soil temperature regimes at lower elevations. Andic Argixerolls with frigid soil temperature regimes predominate at higher elevations. The climate is characterized by warm dry summers and cold wet winters. Annual precipitation is approximately 460 mm and falls primarily as snow from October through May. Mean air temperatures usually range from -9 to 29°C.

The overstory vegetation on the experimental forest is dominated by ponderosa pine (***Pinus ponderosa*** Dougl. ***ex*** Laws.) with varying amounts of white fir (***Abies concolor*** (Gord. & Glend.) Lindl. ***ex*** Hildebr.), incense-cedar (***Calocedrus decurrens*** (Torr.) Florin), and Jeffrey pine ***(Pinus jeffreyi*** Grev. & Balf.) (Oliver 2000). The understory contains abundant regeneration of both ponderosa pine and white fir. The five shrub species accounting for most of the ground cover are: greenleaf manzanita (***Arctostaphylos patula*** Greene), prostrate ceanothus (***Ceanothus prostratus*** Benth.), snowbrush (***Ceanothus velutinus*** Dougl. ex Hook.), antelope bitterbrush (***Purshia tridentata*** (Pursh) DC), and creeping snowberry (***Symphoricarpos mollis*** Nutt.).

EXPERIMENTAL TREATMENTS

The study covers 1,226 ha of the experimental forest and 111 ha of the adjacent national forest. Silvicultural treatments and grazing have been imposed under a completely randomized split-plot design (Figure 1), with combinations of structural diversity (high vs. low) of the residual stand and grazing (grazed vs. ungrazed) as the main plot factors and with (F) and without (NoF) prescribed fire as the subplot factor (Oliver and Powers 1998, Oliver 2000). Whole-plot experimental units ranged from 77 to 144 ha (μ = 111 ha) and were blocked by proportion of species composition rather than geographic proximity because white fir and incense-cedar become increasingly abundant at the higher elevations in the forests. The two structural treatments were randomly assigned to six experimental units each. The high structural diversity (HiD) treatment was designed to leave all

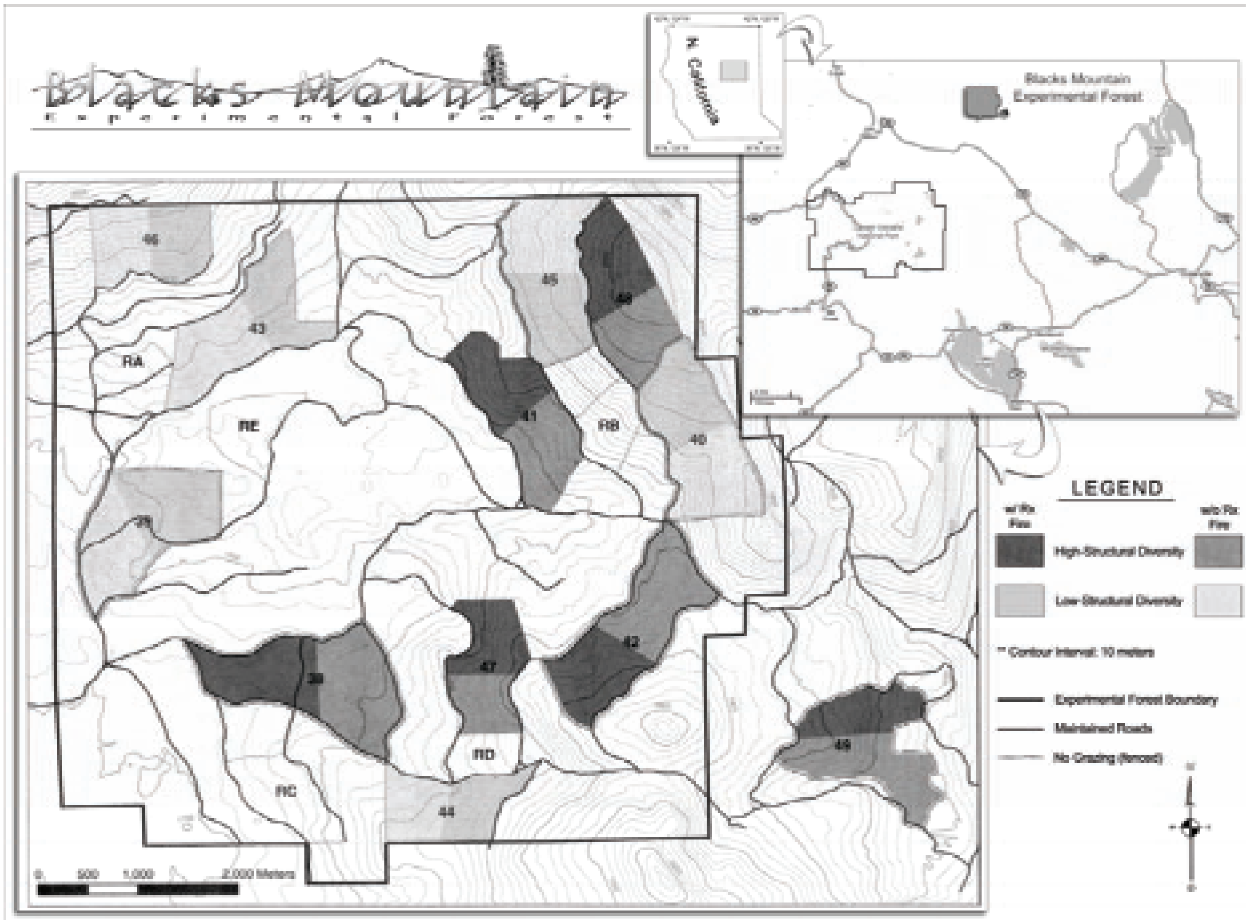

Figure 1— Location of the Blacks Mountain Experimental Forest and layout of the Blacks Mountain Ecological Project in northeastern California, USA.

large, old dominant trees, abundant snags, multiple canopy layers with dense clumps of smaller trees, and many canopy gaps and forest floor openings (Oliver and Powers 1998, Oliver 2000). The low structural diversity (LoD) treatment produced a single canopy layer of well-spaced co-dominant trees, few snags, and few large canopy gaps and forest floor openings (Figure 2). Five Research Natural Areas, which are not included in this study, are well-distributed within Blacks Mountain Experimental Forest (Figure 1) and could provide information on untreated stands.

Because of large plot size, treatment implementation took several years. Three individual blocks, each with two HiD units and two LoD units were created in 1996, 1997, and 1998 respectively. The prescribed fire was planned for the fall of the following year. Because the conditions needed to meet the burning prescription could not be met in 1998, prescribed fire for blocks two and three were delayed to the fall of 1999 and 2000 respectively. Duff litter around existing snags was raked prior to application of prescribed fire.

Six of twelve units were fenced to exclude grazing in the summer of the following year when the structural diversity treatment was applied. After treatment installation, an interdisciplinary team of scientists observed that our grazing treatment has not been effective because grazing intensity is largely a function of proximity to water, which limits most grazing to block one. In addition, a preliminary analysis indicated that there was no significant grazing effect for all variables measured. Therefore, the grazing treatment will not be considered in the analysis, thus doubling the replications within each block.

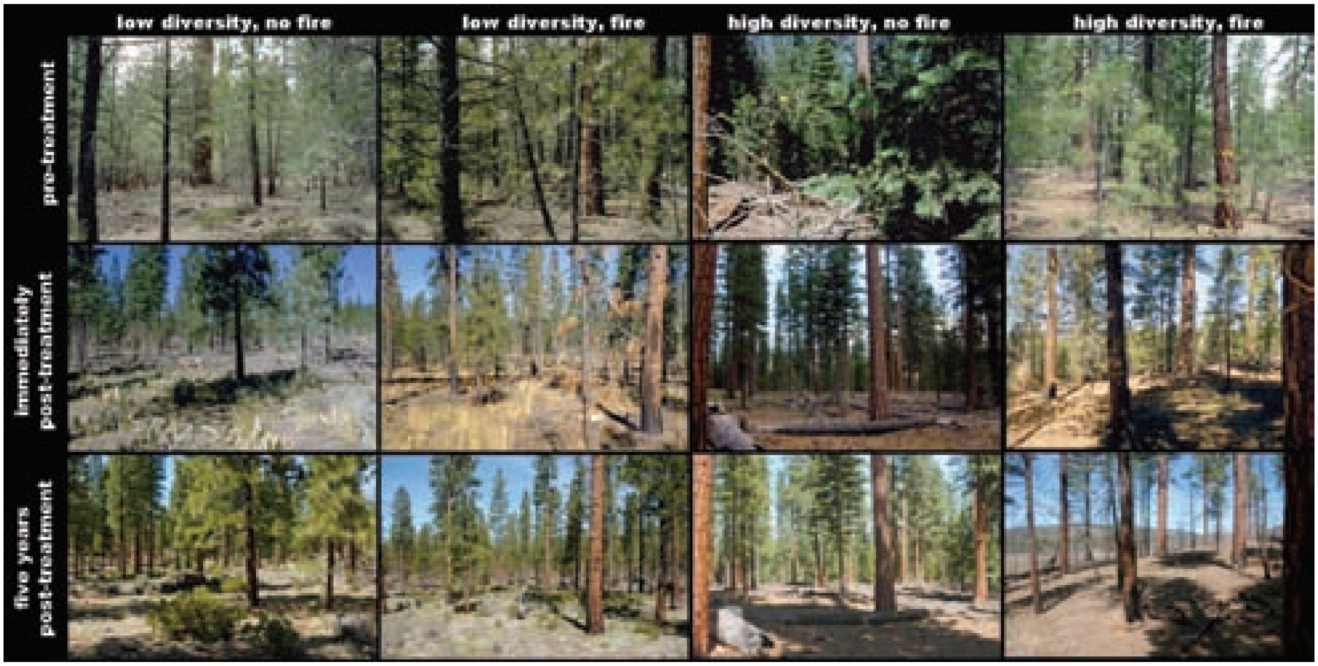

Figure 2— Stand structure and species composition on low structural diversity without prescribed fire, low structural diversity with prescribed fire, high structural diversity without prescribed fire, and high structural diversity with prescribed fire in the pre-treatment, immediate post-treatment, and five years after post-treatment at the Blacks Mountain Ecological Project in northeastern California, USA.

SAMPLING PROCEDURES

Throughout each of the experimental units, a permanently monumented grid on 100-m centers was installed (Oliver 2000). The monuments were located by conventional survey methods. Actual location of each monument was within 6 inches. Monuments are 46-cm rebar with an aluminum cap stamped with the main plot number and Universal Transverse Mercator (UTM) coordinate. All measurements were referenced to these grid points. Among variables that have been measured, trees were most intensively measured; the detailed methods were described in Zhang et al (2008). For example, a pre-treatment tree inventory (DBH > 9.1 cm) was conducted in 1994, with a 25 % grid point sampling intensity. The purpose of the pre-treatment inventory was to collect the baseline data that was utilized to designate the block and unit layout. The post-treatment inventories were more intensive with 50% of the grid points systematically sampled in the year following the prescribed fire application (1998, 2000, and 2001). Every tree with DBH > 9.1 cm DBH has been tagged. As part of the study, the plots are scheduled to be re-measured every five years after the first post-treatment inventory. The second post-treatment re-measurements were conducted in 2003, 2005, and 2006 by blocks.

Understory woody plants, species number and cover percentage were also measured during the post-treatment survey (Zhang et al. 2008). Dead woody materials were measured prior to and post treatment (Brown 1974; F.C.C. Uzoh and C.N. Skinner, unpublished data). A census of bark beetle-induced mortality was established (Fettig et al. 2008). Because there have been many more measurements conducted in the study, we are only focusing on a few variables that have been thoroughly analyzed.

TREATMENT EFFECTS ON FOREST COMPONENTS

Dead woody fuels on the forest floor

Dead woody materials were sampled with the planar intercept method before the treatment was installed in 1994 and one year following treatment. Volume (m^3 ha^{-1}) of sound and decayed woods were separately calculated and converted to dry weight (Mg ha^{-1}) using method of van Wagtendonk et al (1996) (F.C.C. Uzoh and C.N. Skinner, unpublished data). Results show that prescribed fire has significantly reduced both sound and rotten woody materials on the forest floor (Figure 3). Effect of structural diversity was not significant. Although woody materials

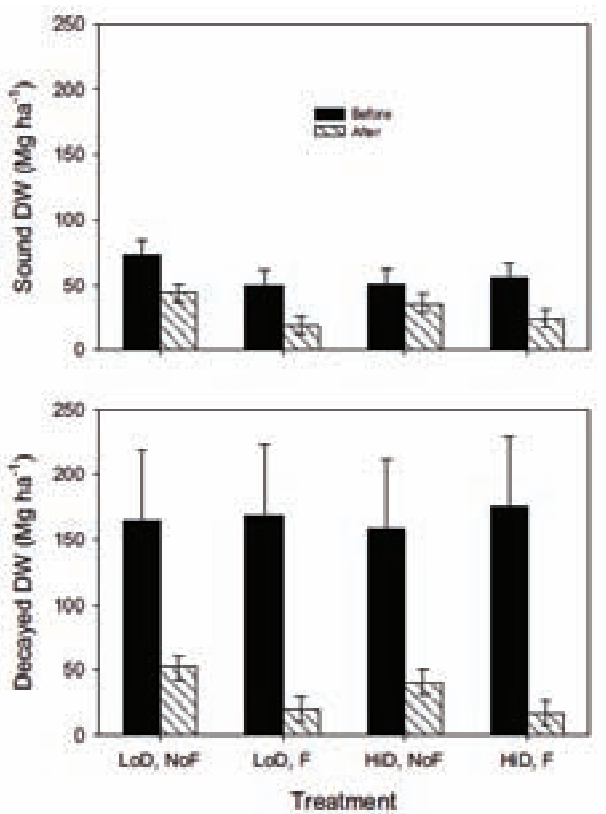

Figure 3— Mean dry weight (±1SE) of sound and decayed dead woody materials (F.C.C. Uzoh and C.N. Skinner, unpublished data) before and after treatments were installed at the Blacks Mountain Ecological Research Project in northeastern California. LoD = low structural diversity, NoF = without prescribed fire, F = with prescribed fire, and HiD = high structural diversity.

with advanced decay were more prevalent than sound woody materials prior to treatments, the amounts were comparable after treatment due to breaking up of larger materials by harvesting machines (Weatherspoon 1983).

Understory woody plants

Using the planar-intercept method on a 100 m transect associated with sampled grid points for the post-treatment measurements, the first post-treatment inventory did not reveal any significant differences in shrub cover or number of species with respect to structural diversity or prescribed fire (Figure 4). Five years later, shrub cover was significantly higher on LoD units, but number of species did not vary with structural diversity. A potential explanation is that tree canopy cover in LoD treatment is much lower than that in HiD treatment (Vaughn and Ritchie 2005). Shrubs may have responded to this with increased growth with more sunlight and perhaps more water available under the more open canopy. However, these treatments did not alter the seed bank or propagules of the existing species before treatment and nor did they appear to create favorable conditions for exotic species.

Stand dynamics

The thinning treatment produced two very different stand structures. The average values of LoD and HiD treatments were 10 vs. 25 m^2 ha^{-1} for BA (Figure 5) and 282 vs. 513 trees ha^{-1} for number of trees (Figure 6), respectively. Based on the initial post-treatment measurements, the upper limit for diameter in LoD units was 60 cm and BA was concentrated between 20 and 40 cm DBH classes. In contrast, HiD treatment maintained trees across a broader range of DBH classes; BA was concentrated between 20 and 80 cm DBH classes (Zhang et al. 2008).

Based on the second post-treatment measurements, structural-diversity effect was still significant in stand BA and density; the average values of LoD and HiD treatments were 11 vs. 25 m^2 ha^{-1} for BA and 258 vs. 487 trees ha^{-1} for

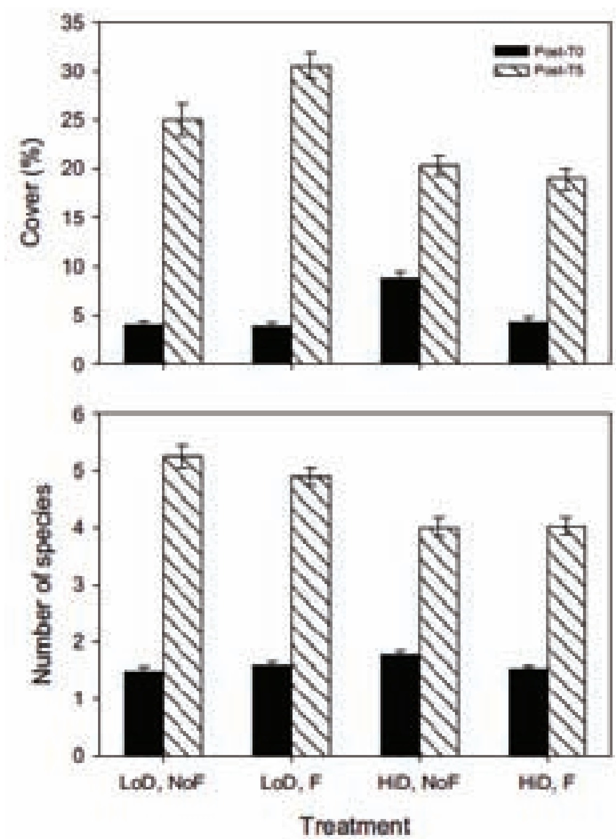

Figure 4— Overall shrub cover (%) and number of species (μ±1se) grown in the treatments at the Blacks Mountain Ecological Research Project measured immediately (Post-T0) and five years (Post-T5) after treatments were installed (Zhang et al. 2008). Abbreviation of x-axis label is in the legend of Figure 3.

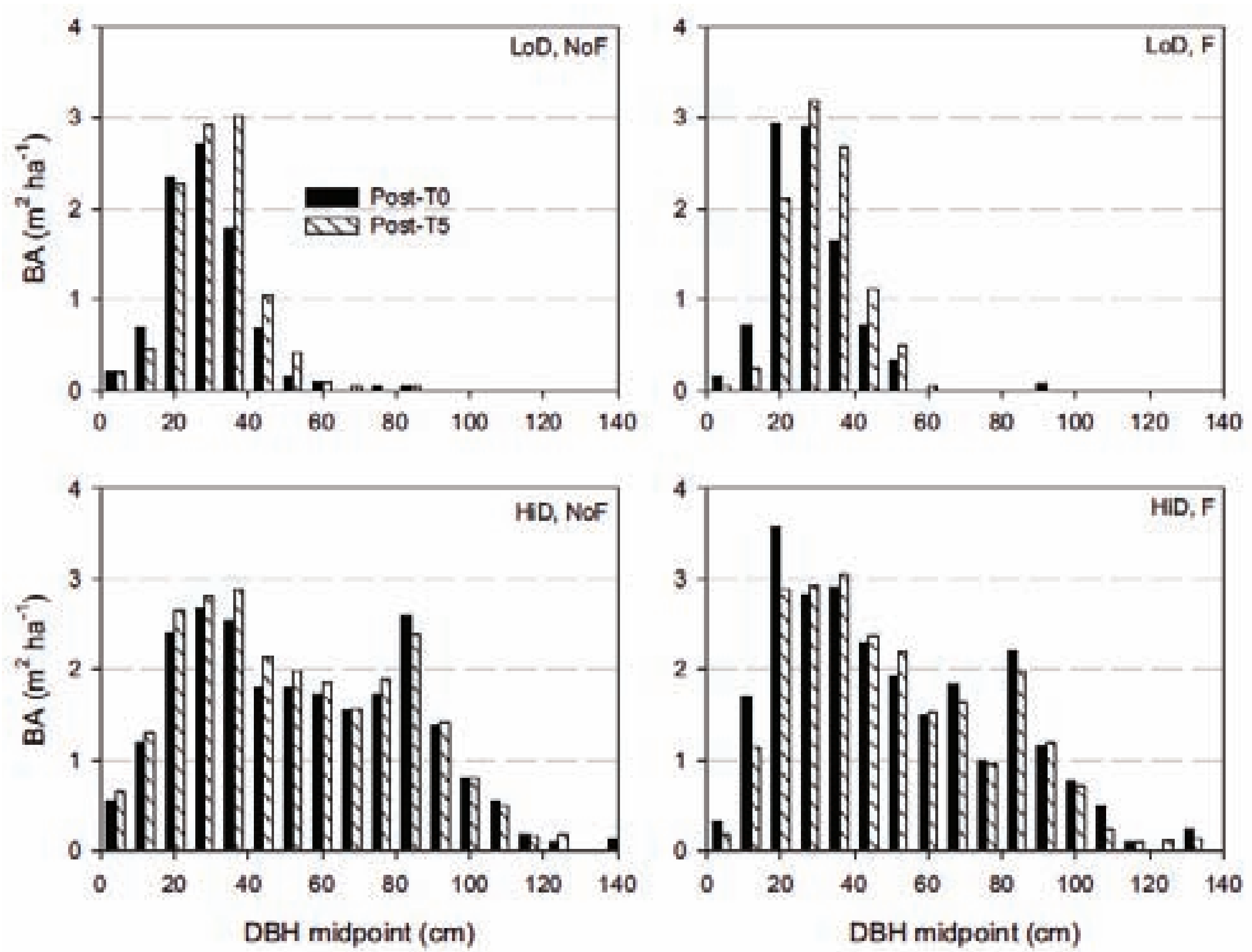

Figure 5 - Diameter-class basal area distributions for trees grown in the LoD (upper two) and in the HiD (lower two) without prescribed fire (left two) and with prescribed fire (right two) at the Blacks Mountain Ecological Research Project measured immediately (Post-T0) and five years (Post–T5) after the treatments were installed.

number of trees, respectively. Prescribed-fire effect was also significant for trees ha^{-1}. Differences were mainly related to mortality caused by prescribed fire and bark beetles. The mortality tended to occur in the smaller DBH classes (<20 cm) (Figures 5 & 6). During the five year period, mean trees ha-1 increased 11% (32 tree ha^{-1}) in the LoD without prescribed fire and decreased 28% (79 tree ha^{-1}) in the LoD with prescribed fire. Similarly, we found a 13% (67 tree ha^{-1}) increase in trees ha^{-1} in the HiD without prescribed fire and a 29% (145 tree ha^{-1}) decrease in the HiD with prescribed fire between the first and second post-treatment measurements. The results demonstrated that prescribed fire damaged or killed some trees. Many trees apparently alive in the first post-treatment measurements died during the next 5 years. Therefore, mortality assessments should consider both primary (directly killed by fire) and secondary (weakened by fire and killed by insects or disease) mortality after the prescribed fire to obtain accurate estimates (McHugh & Kolb 2003).

Stand diameter (QMD) grew significantly more in LoD treatment (0.65 ± 0.02 cm yr^{-1}) than in the HiD treatment (0.33 ± 0.01 cm yr^{-1}) (Figure 7). Effect of structural diversity was not significant for PAI BA, although PAI BA was slightly higher for the LoD treatment (0.38 ± 0.02 m^2 ha^{-1} yr^{-1}) than for the HiD treatment (0.34 ± 0.02 m^2 ha^{-1} yr^{-1}). Trees surviving fire grew as much as trees without fire, confirming that low intensity surface fires may not affect tree growth (Busse et al. 2000; Ritchie and Harcksen 2005).

Stand productivity based on living trees measured at both times may be underestimated for the LoD plots rela-

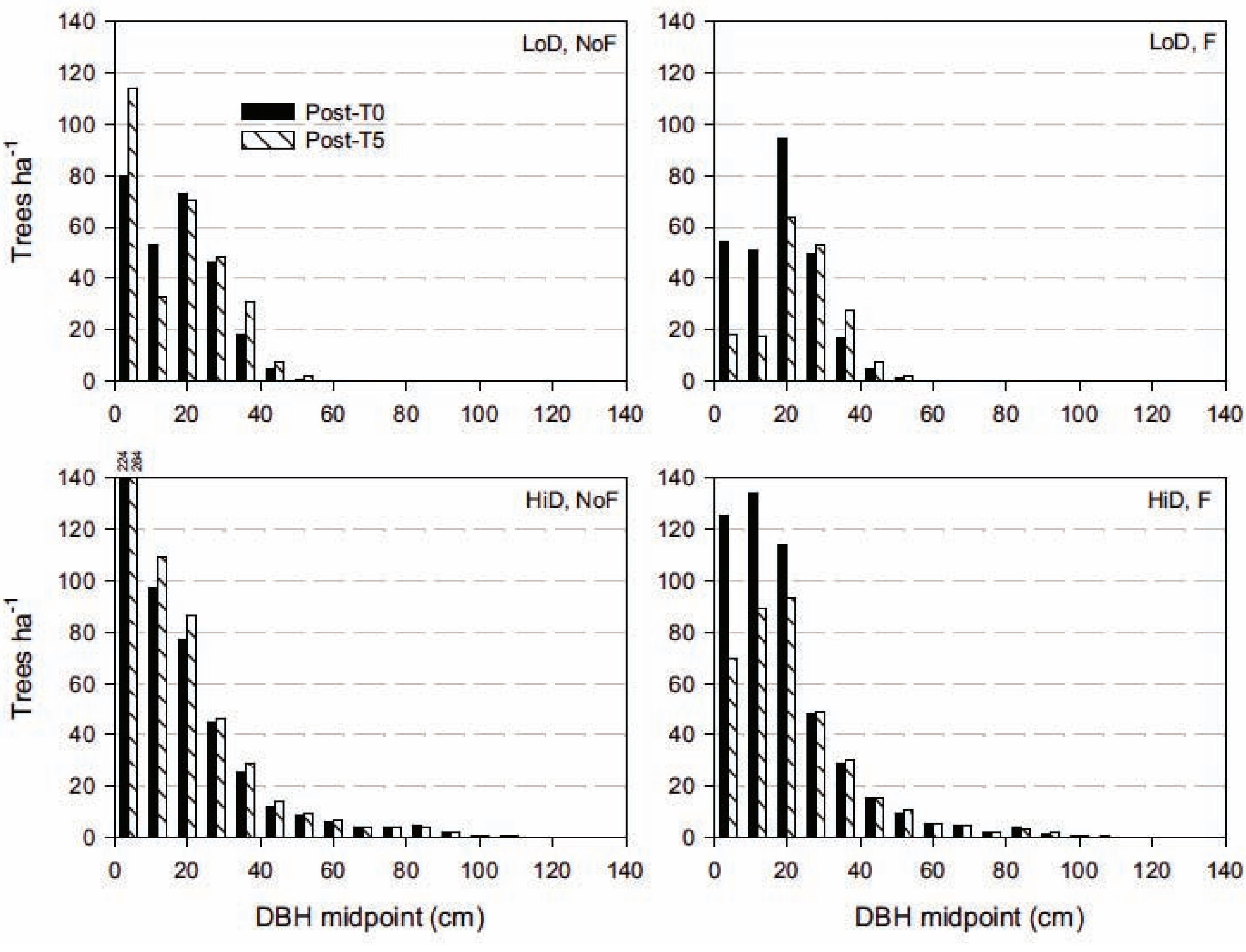

Figure 6 - Diameter-class frequency distributions for trees grown in the LoD (upper two) and in the HiD (lower two) without prescribed fire (left two) and with prescribed fire (right two) at the Blacks Mountain Ecological Research Project measured immediately (Post-T0) and five years (Post–T5) after the treatments were installed.

tive to the HiD plots if the Langsaeter's growth curve was considered (sensu Daniel et al. 1979, p. 318). When an old stand was thinned, annual increment in the earlier periods was strongly related to the initial stand density as found on other long-term density studies in ponderosa pine (Cochran and Barrett 1993, Oliver 1997, Zhang et al. 2006). The trend would not change until the onset of inter-tree competition occurs again (Smith et al. 1997, Zhang et al. 2006). In this regard, it is perhaps surprising that the LoD plots, which carry less than half the BA of the HiD plots, showed such elevated growth levels. If we considered growth proportion by dividing by initial BA to compare both treatments, the LoD would have showed even higher percentage growth (0.38/10 = 3.8% yr^{-1}) than the HiD would (0.34/25 = 1.4% yr^{-1}).

Large trees in the HiD

One of the objectives in restoring ponderosa pine ecosystems is to improve the health of large dominant trees by minimizing environmental stresses. Risk rating is one metric for tree health (Keen 1943; Salman and Bongberg 1942). Evaluating risk rating for the large trees (DBH > 60 cm) in the HiD units, Ritchie et al. (2008) found far fewer of these trees were rated as "high-risk" than the large trees grown on adjacent untreated Research Natural Areas (Figure 8), although the number of large trees was approximately the same on both HiD and RNA. This trend held in both burned and unburned units. Both treatments appear to improve the health of these large dominant trees.

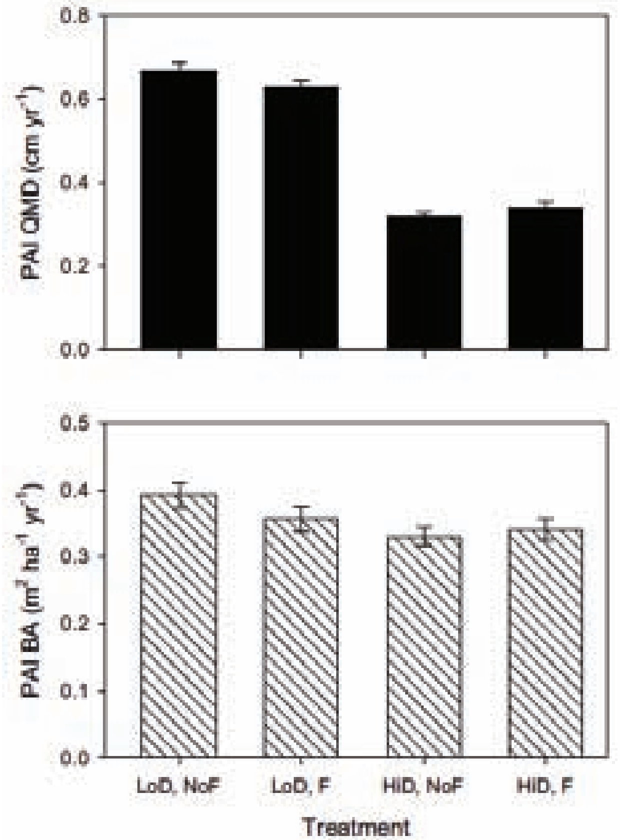

Figure 7— Average (μ±1se) periodic annual increment (PAI) for quadratic mean diameter (QMD) and basal area (BA) for different treatments calculated from first post-treatment measurements and second post-treatment measurements (redrawn from Zhang et al. 2008). Abbreviation of x-axis label is in the legend of Figure 3.

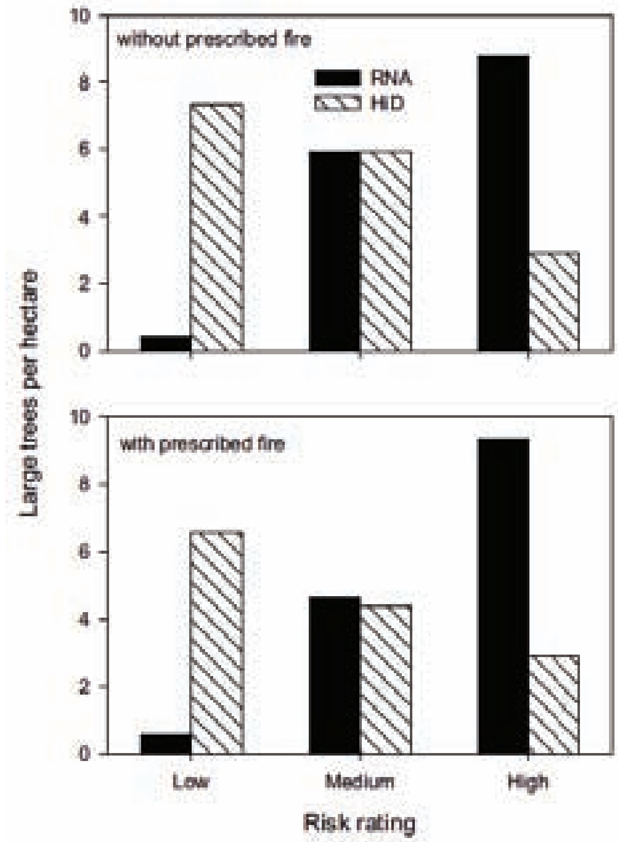

Figure 8— Large trees (DBH > 60 cm) per hectare sorted by risk rating observed from the high structural diversity (HiD) treatment and adjacent Research Natural Area (RNA) without and with prescribed fire at the Blacks Mountain Experimental Forest. Figures were drawn based on data of Ritchie et al. (2008).

Bark beetle colonization

Bark beetles attack significantly more trees on plots in prescribed fire splits than on plots without prescribed fire, regardless of structural diversity (Figure 9). About 86% of bark beetle-caused mortality occurred in the prescribed fire splits, mainly in smaller diameter classes (Fettig et al. 2008). This result may explain the significantly different mortality between the first and second post-treatment measurements within the prescribed fire split. Therefore, secondary mortality may be expected even when initial fire-caused mortality is low because prescribed fire weakens trees that are susceptible to the bark beetle attack. It is not known if this same phenomenon will be observed with later applications of prescribed fire in stands with more vigorous trees and healthier crowns.

IMPLICATIONS

Across northeastern California, many crowded ponderosa pine forests are threatened by severe, stand replacing fire and bark beetle outbreaks. Forest managers are very interested in using silvicultural tools to restore resilience in these ecosystems. Because the problems have resulted from decades of fire exclusion combined with inadequate stand density management in this fire-adapted ecosystem, they cannot be solved overnight. This project demonstrates a good start, by successfully using thinning and/or prescribed fire to treat these forests. The treated stands contain much fewer high-risk trees than untreated stands, suggesting that the health of the treated stands has been improved within five years. Based on results of dead woody materials and shrub cover for the initial five years, it appears that the dead woody fuels on forest floor only respond to prescribed fire (Figure 3) while the growth of shrubs is significantly associated with over-story structural diversity but not

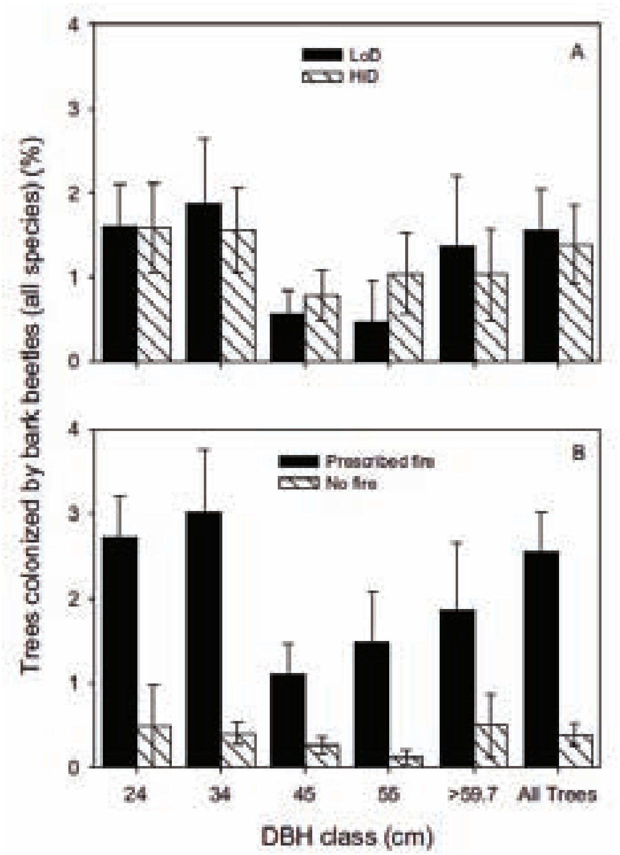

Figure 9— Mean (μ±1se) percentage of tree colonized by bark beetles (all species combined) by diameter class for all trees by structure treatment (A) and with and without prescribed fire (B) at the Blacks Mountain Ecological Research Project (redrawn from Fettig et al. 2008).

with prescribed fire (Figure 4). These results may explain the findings by Ritchie et al. (2007) that a combination of thinning and prescribed fire is more effective than thinning only at reducing wildfire severity.

The stand structures considered in this study are representative of two contrasting management priorities. The LoD stand is consistent with a timber production emphasis – maintaining thrifty fast-growing trees — yielding a much higher rate of growth both for individual trees and at the stand level. The HiD stand is consistent with an emphasis on maintenance of a range of tree sizes that may be more consistent with historic (pre-settlement) conditions. This increase in structural diversity comes at a significant loss in productivity. This cost may be offset by other amenities (e.g. wildlife habitat, visual resources) that they may provide. With either type of stand structure, use of prescribed fire may be beneficial in maintaining the health and vigor of these stands in the long term. However its application may reduce the occurrence of snags and woody debris, and both of these contribute to wildlife habitat.

LITERATURE CITED

Brown, J. K. 1974. Handbook for inventorying downed woody material. USDA Forest Service Gen. Tech Rep. INT-16.

Busse, M.D., Simon, S.A., and Riegel, G.M. 2000. Tree growth and understory responses to low-severity prescribed burning in thinned Pinus ponderosa forests of central Oregon. For. Sci. 46:258-268.

Cochran, P.H. and Barrett, J.W. 1993. Long-term response of planted ponderosa pine to thinning on Oregon's Blue Mountains. West. J. Appl. For. 8:126-132.

Daniel, T.W., Helms, J.A., and Baker, F.S. 1979. Principles of silviculture. Second edition, McGraw-Hill Book Company. 500p.

Fettig, C.J.; Borys, R.R.; McKelvey, S.R.; Dabney, C.P. 2008. Blacks Mountain Experimental Forest: bark beetle responses to differences in forest structure and the application of prescribed fire in interior ponderosa pine. Can. J. For. Res. submitted.

Keen, F.P. 1943. Ponderosa pine tree classes redefined. J. Forestry 41(4):249-253.

Kessler, W.B.; Salwasser, H.; Cartwright, C.W.; Caplan, J.A. 1992. New perspectives for sustainable natural resources management. Ecol. Appl. 2(3):221-225.

McHugh, C.W., and Kolb, T.E. 2003. Ponderosa pine mortality following fire in northern Arizona. Int. J. Wildl. Fire 12:7-22.

National Research Council. 1990. Forest research: a mandate for change. National Academy Press, Washington, D.C., USA.

Oliver, W.W. 1997. Twenty-five-year growth and mortality of planted ponderosa pine repeatedly thinned to different stand densities in northern California. West. J. Appl. For. 12:122-130.

Oliver, W.W. and Powers, R.F. 1998. Blacks Mountain, California: interdisciplinary field research in ponderosa pine. J. Forestry 96(8):4-9.

Oliver, W.W. 2000. Ecological research at the Blacks Mountain Experimental Forest in northeastern California. USDA For. Serv. Gen. Tech. Rep. PSW-GTR-179. Albany, CA: Pacific Southwest Research Station, 66 p.

Ritchie, M.W., and Harcksen, K.A. 2005. Accelerating development of late-successional features in second-growth pine stands of the Goosenest Adaptive Management Area. in: Proceedings of the symposium on ponderosa pine: issues, trends, and management. 18-21 October, 2004, Klamath Falls, OR. Compiled by M. W. Ritchie, D. A. Maguire, and A. Youngblood. Gen. Tech. Rep. PSW-GTR-198. Albany, CA. Pacific Southwest Research Station. pp 81-93.

Ritchie, M.W., Skinner, C.N., and Hamilton, T.A. 2007. Probability of wildfire-induced tree mortality in an interior pine forest: effects of thinning and prescribed fire. For. Ecol. Manag. 247:200-208.

Ritchie, M.W.; Wing, B.M.; Hamilton, T.A. 2008. Maintaining stability of the large tree component in a late-seral interior ponderosa pine forest. Can. J. For. Res. submitted.

Salman, K.A.; Bongberg, J.W. 1942. Logging high risk trees to control insects in the pine stands of northeastern California. J. Forestry 40(7):533-539.

Smith, D.M., Larson, B.C., Kelty, M.J., and Ashton, P.M.S. 1997. The practice of silviculture: applied forest ecology. John Wiley & Sons, Inc. 537p.

USDA Forest Service. 1990. Strategy for the 90's for USDA Forest Service Research. United States Department of Agriculture, Washington, D.C., USA.

van Wagtendonk, J.W.; Benedict, J.M.; Sydoriak, W.M. 1996. Physical properties of woody fuel particles of Sierra Nevada conifers. Inter. J Wild. Fire 6:117-123.

Vaughn, N.; Ritchie, M.W. 2005. Estimation of crown cover in interior ponderosa pine stands: effect of thinning and prescribed fire. West. J. Appl. For. 20(4):240-246.

Weatherspoon, C.P. 1983. Residue management in the eastside pine type. In: Management of the eastside pine type in northeastern California: proceedings of a symposium, 15-17 June 1982, Susanville, California. Edited by Robson, T.F.; Standiford, R.B. Northern California Society of American Foresters, Arcata, California, pp. 114-121.

Wilkinson, C.F.; Anderson, H.M. 1987. Land and resource planning in the national forests. Island Press, Washington, D.C., USA.

Zhang, J.W., Oliver, W.W. and Busse, M.D. 2006. Growth and development of ponderosa pine on sites of contrasting productivities: relative importance of stand density and shrub competition effects. Can. J. For. Res. 36:2426-2438.

Zhang, J.W.; Ritchie, M.W.; Oliver, W.W. 2008. Vegetation responses to stand structure and prescribed fire in an interior ponderosa pine ecosystem. Can. J. For. Res. submitted.