EXPLORING METHODS FOR MAINTAINING OLD-GROWTH STRUCTURE IN FORESTS WITH A FREQUENT-FIRE HISTORY: A CASE STUDY

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ABSTRACT

The management of old-growth forests in the Pacific Northwest continues to be a controversial issue because of the special values society associates with old-growth reserves. Current management of federal old-growth reserves is a "hands-off" approach. In the dry forest types of eastern Oregon, old-growth forests have changed dramatically in the last 80–90 years primarily as a result of fire exclusion, with Douglas-fir and grand fir invading the mid- and understory canopy layers, intensifying competition, and placing the old-growth trees at increasing risk to insects, disease, and stand-replacing fire. In 1993, Oregon State University initiated a case study to examine alternatives for maintaining old-growth forests in the Blue Mountains of northeast Oregon to test the hypothesis that managed old-growth stands, where density and composition are maintained at historic levels, remain viable longer as old-growth habitat than do currently reserved or unmanaged old-growth areas. We selected 2 stands having old-growth characteristics that had significant understory development of Douglas-fir and grand fir. A nearby old-growth reserve area served as a control. We used the Region 6 Interim Old Growth Definitions for the grand fir/white fir series as a guide for developing our old-growth prescriptions and tree marking guidelines. In our tree marking guidelines, we allocated most of the residual basal area to the large trees but left trees in the midstory layer as well. We removed a heavy proportion of Douglas-fir and grand fir in the under- and midstory canopy layers. Small-diameter ponderosa pine in the 10–20 centimeter diameter range were thinned to improve vigor and provide for replacement trees. Gaps and openings up to 0.4 hectares in size were also created to provide for ponderosa pine regeneration and understory development.

Only 1 of the 2 treatment stands was thinned to the desired density and stand targets. The thinning of the 1 stand reduced basal area per hectare and stand density index (SDI) by 61% and 62%, respectively. Preliminary results after 3 years of measurement indicate that vigor of residual old-growth trees, as measured by cambial electrical resistance, appears to be increasing as stand density is reduced. The thinning of the 1 stand removed nearly all fuel ladders and reduced crown and canopy density. An underburn in this stand consumed most of the slash created by the thinning activity. Thus, the potential for stand-replacement fire has been greatly reduced.

This case study demonstrates a methodology for restoring historic stand structure in old-growth forests in the dry forest types of eastern Oregon to improve old-growth tree vigor and to maintain these stands on the landscape for a longer time. Questions remain about whether we were too late in intervening. Old-growth management strategies for the future should determine where on the landscape old-growth structure is needed and how much is needed, and perhaps accelerate the development of old-growth characteristics in younger stands to provide replacement.

keywords: fire ecology, fire history, forest management, mixed conifer forests, old-growth management, ponderosa pine forests.

Citation: Fitzgerald, S.A., W.H. Emmingham, G.M. Filip, and P.T. Oester. 2000. Exploring methods for maintaining old-growth structure in forests with a frequent-fire history: a case study. Pages 199–206 *in* W. Keith Moser and Cynthia F. Moser (eds.). Fire and forest ecology: innovative silviculture and vegetation management. Tall Timbers Fire Ecology Conference Proceedings, No. 21. Tall Timbers Research Station, Tallahassee, FL.

INTRODUCTION

An important issue facing land managers today is the development, maintenance, and management of old-growth forests (Dolph et al. 1995). Because of harvest and liquidation of old-growth forests earlier in this century, late-successional and old-growth forests have steadily declined in area (Lehmkuhl et al. 1993, Scientific Society Panel 1993). Many interest groups and the general public are concerned about the management of remaining old-growth tracts because of the tangible and intangible values associated with them. Old-growth areas provide sources of high-quality timber, habitat for late-successional wildlife species, landscape and genetic diversity, watershed protection, recreation, and places that are viewed as natural or "pristine" and are the last vestige of our original forests.

Because management of old-growth forests in the Pacific Northwest has become a political matter (Allen 1993) in recent years, the current management strategy is to draw a line around designated old-growth areas and call them off-limits to any kind of *active* management. A continued "hands-off" approach, however, may spell eventual doom for many old-growth areas in eastern Oregon and across the interior West because this policy ignores the very processes that historically shaped their development—principally, the role of regular disturbance by fire.

Disturbance Ecology of Interior, Dry Site Forests

Disturbances, such as periodic insect outbreaks, disease, fire, wind, and wildlife browsing, have shaped and dramatically influenced the structure of forest stands and of entire landscapes across eastern Oregon. Of all these disturbances, fire historically may have had the greatest large-scale influence on forests. Fire creates a seedbed for regeneration of trees, shrubs, and herbaceous species, cycles nutrients, affects successional patterns, influences the mosaic of age classes, influences species composition and stand structure, and affects the accumulation and consumption of living and dead fuels (Kilgore 1973).

Indeed, fire history studies reveal that fire frequently occurred in the dry forest types of the interior West. In both the climax ponderosa pine (*Pinus ponderosa*) and dry mixed conifer forest types, fire occurred approximately every 3–30 years (Weaver 1943, 1959, Soeriaatmadja 1966, Hall 1976, 1980, Arno 1980, Bork 1985, Barrett et al. 1997). These fires were relatively "cool" and mainly confined to the forest floor, thereby maintaining large-diameter trees in open, parklike stands. Few snags and downed logs were present in these fire-maintained old-growth ponderosa pine forests (Munger 1917). On dry mixed conifer sites, frequent fire removed such thin-barked species as grand fir (*Abies grandis*) and young Douglas-fir (*Pseudotsuga menziesii*). Seral ponderosa pine and western larch (*Larix occidentalis*) remained dominant. Thus, on a fairly frequent basis, both density *and* composition were "adjusted" by fire.

Over the last 80–100 years fire has been excluded from many plant associations in the interior West. Without regular fire forest succession has continued unchecked, resulting in stand densities that have increased from 25–74 trees per hectare (10–30 trees per acre) to >2,964 trees per hectare (1,200 trees per acre) (Covington and Moore 1992, Adams 1995, Covington et al. 1997). On more mesic sites, formerly pine/larch-dominated stands are now dominated by shade-tolerant Douglas-fir and true firs. In addition, removal of ponderosa pine, western larch, and other seral species during selective timber harvests has accelerated the development of understory fir species on mixed conifer sites (Wickman 1992).

Increases in stand density and shifts in composition and structure have increased the susceptibility of interior forests to insects, diseases, and other pathogens across millions of hectares in the interior Columbia River Basin of Oregon, Washington, and Idaho (Hessburg et al. 1993, Mason and Wickman 1993), resulting in some of the largest insect infestations we have seen in recent decades. Centuries-old ponderosa pine and other large-diameter trees species have become particularly prone to bark beetle attack. Live and dead fuel accumulation has correspondingly increased. Scientists and land managers generally agree that fire regimes have changed in the pure ponderosa pine and dry mixed conifer types over the last 80–100 years. Today, the fires burn with greater intensity and are stand-replacing, rather than confined to the understory (Quigley and Arbelbide 1996). Many old-growth stands no longer qualify as old-growth habitat because of accelerated mortality of the large tree component, and increases in fuel loading place old-growth stands at greater risk (Harrington and Sackett 1992). Thus, the resiliency and sustainability of old-growth forests is in question.

How do land managers go about developing strategies that maintain old-growth stands for the long term, while other areas are allowed to grow into or are directly manipulated to develop mature forest structure in a shorter time? The historic disturbance pattern that shaped the development of old forests over several millennia may serve as the strategic "blueprint." Several researchers have proposed such strategies as cutting trees (primarily understory trees), prescribed underburning, or both (Covington and Moore 1992, 1994, Mutch et al. 1993, Johnson 1994, Covington et al. 1997). To date, few examples of such forest restoration and maintenance exist in the Pacific Northwest.

In 1992 Oregon State University developed the Genesis Research and Demonstration Project in partnership with the Malheur National Forest to test alternative silvicultural systems on sites heavily impacted by insects and disease and at increasing risk of stand-replacement fire. The silvicultural systems tested included individual tree selection, group selection, and an old-growth "maintenance" treatment. The old-growth maintenance treatment was devised to test the hypothesis that managed old-growth stands—where density and composition are maintained at historic levels—remain viable longer as old-growth habitat than do currently reserved or unmanaged old-growth stands. This paper reports the methodology used to develop the old-growth maintenance treatment and discusses the implementation phase of the study.

DESCRIPTION OF STUDY

Study Site and Stand Conditions

The Genesis Research and Demonstration area involved approximately 2,400 hectares and is located on the Prairie City Ranger District on Malheur National Forest near John Day, in the Blue Mountains of northeast Oregon. The study area lies on a west- to southwest-facing slope at an elevation of about 1,370 meters on a dry grand fir plant association (Hall 1973).

Prior to the early 1980's the project area had not been entered for timber harvest. Thirty percent of the area underwent commercial thinning and regeneration harvests (clear-cutting and shelterwood) in the early 1980's. The land historically has been used for livestock grazing, which continues today.

The project area contains an overstory of ponderosa pine intermixed with Douglas-fir, grand fir, and western larch. Fire exclusion has allowed shade-tolerant grand fir and Douglas-fir to increase in the mid-canopy and understory layers, creating multi-layered forests (Figure 1a, b). Overstory ponderosa pine is uneven-aged in character, with a majority of trees in the 140–200 year old age classes. The oldest ponderosa pine we aged was 320 years old. Few ponderosa pine were <100 years old.

Defoliation by western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orgyia pseudotsugata*) from the early 1980's – 1992 caused severe damage and mortality of grand fir and Douglas-fir. Secondary bark beetle (*Dendroctonus* spp.) attack resulted in additional mortality of stressed trees. At the time the study was established, only 7% of the area was considered healthy and sustainable (U.S. Department of Agriculture [USDA], Forest Service 1992*a*). Another 30% of the project area was unhealthy, but contained a good component of ponderosa pine, western larch, and Douglas-fir in the mid- and overstory layers to provide shelter, seed, and genetic diversity for regeneration. Ponderosa pine regeneration was absent on the forest floor over most of the study area.

Riparian and old-growth stands suffered the most from insect defoliation because of their multiple-canopy structure and because riparian vegetation was dominated by grand fir and Douglas-fir. Subsequent mortality in these stands has increased the amount of standing and down dead stems, thus increasing wildfire hazard and risk.

Surprisingly, many mid- and understory fir trees survived the defoliation. Although defoliation may reduce competition between surviving trees and potentially benefit the old-growth ponderosa pine, the benefits may be temporary as the fir trees refoliate and begin consuming more site resources. Increasing competition over the last 80 years has stressed the overstory old-growth ponderosa pine; mortality of these large trees appears to be increasing.

Fig. 1. An old-growth ponderosa pine stand (a) and an old-growth ponderosa tree with a large fire scar (b) showing the dense condition that has developed in the Malheur National Forest, OR, as a result of fire exclusion on a mixed conifer site.

Description of Treatments

Definitions for old-growth structure usually include a range for each of the following structural attributes (Franklin et al. 1981, Mehl 1992): (1) number of trees per hectare >53.0 centimeters (21.0 inches) in diameter, (2) number of snags per hectare, (3) amount of coarse woody debris per hectare, (4) number of canopy layers, (5) percent cover of shrubs and herbs, (6) size and number of gaps within a stand, and (7) stand or patch size.

The quantity required for each of these structural components varies from one forest type or plant association to another. We used Region 6 Interim Old Growth Definitions for the grand fir/white fir series (USDA Forest Service 1992*b*) to identify and screen stands possessing old-growth characteristics from the District's stand examination data. Existing designated old-growth stands in the study area were off-limits to treatment, but they were screened to assess their potential use as controls (no treatment) for the study. From this screening process, 2 stands of 16–20 hectares were identified as having old-growth characteristics, Old-Growth-A (OGA) and Old-Growth-B (OGB).

Table 1. Stand characteristics for stands Old-Growth-A (OGA), Old-Growth-B (OGB), and Old-Growth-C (OGC) (no treatment).

Stand	DBH_q[a]	Trees/ hectare[b]	Basal area/ hectare[c]	SDI
OGA	51	1,052	38	546[c] (299)[d]
OGB	53	2,475	33	462 (250)
OGC	64	701	34	442 (230)

[a] DBH_q (quadratic mean diameter at breast height) includes all trees >12.7 centimeters in diameter at breast height (DBH).
[b] Includes all trees >0.3 meters in height.
[c] Includes all trees >1.37 meters in height.
[d] Includes all trees >1.37 meters in height up to 50.5 centimeters DBH.

Table 2. Summary of stand structural targets for old-growth maintenance treatment.

Structural feature	Target
1. Number of large trees ≥53.0 centimeters (21.0 inches) DBH:	30–42 trees per hectare (12–17 per acre)
2. Basal area:	14–18 square meters per hectare (60–80 square feet per acre) in large trees; leave viable trees in mid- and understory canopy layers.
3. Snags ≥41.0 centimeters (16.0 inches) DBH:	5 per hectare (2 per acre)
4. Course woody debris:	12 pieces ≥30.0 centimeters per hectare (5 pieces ≥12.0 inches per acre)
5. Canopy layers:	2 layers.
6. Grass/herb/shrub:	increase percent cover and productivity.
7. Gaps and openings:	up to 0.4 hectares (1 acre) in size.

A nearby reserved old-growth stand with similar site and stand characteristics served as our control (OGC). Stands OGA and OGC were adjacent to one another. Stand OGA was located approximately 4 kilometers northwest of OGB and OGC. Two of the 3 stands had quadratic mean diameters at breast height (1.4 meters [DBH]) ≥53.0 centimeters (Table 1). The number of trees per hectare and basal areas for these stands are considered high for this plant association compared to historic conditions.

Stand density index (SDI) (Reineke 1933) is also quantified for each stand in Table 1. SDI is the equivalent number of trees per hectare when the quadratic mean diameter is 25.4 centimeters. Because SDI is related to leaf area index (LAI), it is a good measure of resource consumption and site occupancy (Long and Dean 1986, O'Hara 1996). SDI is determined from the following equation:

$$SDI = tpha(DBH_q/25.4)^{1/6}$$

Where:

tpha = trees per hectare

DBH_q = quadratic mean diameter in centimeters

All 3 stands have SDI levels that indicate high competition levels, making the large old-growth ponderosa pine vulnerable to bark beetle attack (Cochran 1992, Cochran et al. 1994). Most of the trees ≥53.0 centimeters in diameter are ponderosa pine and Douglas-fir, with a small percentage of western larch and grand fir. Most of the large grand fir showed signs of extensive stem decay caused by wounding from past surface fires.

Over 50% of tree occupancy in all 3 stands, as measured by SDI (compare SDI total with SDI in parentheses in Table 1), is of trees ≤50.5 centimeters in diameter, mostly comprising Douglas-fir and grand fir. The age of trees ≤50.5 centimeters in diameter was found to be ≤80 years. Thus, since the era of fire suppression, an increasing and significant amount of the growing space is being used by the mid- and understory layers, increasing the competitive pressure on the older, overstory trees.

Sampling

Sample plots were established in all 3 stands using a systematic grid pattern. We established enough plots in each stand to maintain a sampling error of ≤10%. A 20-BAF (Basal Area Factor) variable radius plot was used for sampling trees ≥12.7 centimeters DBH. We sampled trees ≤12.5 centimeters DBH and ≥30.5 centimeters tall on fixed-radius plots of 3.6 meters (hundredth-acre plots). Tree diameter, species, crown class, crown ratio, mortality, and health condition (presence of insects, disease, and mistletoe) were recorded. Tree heights were measured and tree age determined from a small sample across the diameter range for each species. All snags were inventoried and a condition class assigned to each. Herbaceous vegetation was inventoried at plot center. We sampled ground fuels on each plot using a modified version of a technique developed by Brown (1974). We remeasured all tree and stand parameters after harvest to establish baseline conditions. Changes in tree and stand attributes, mortality and regeneration, fuels, and understory conditions will be monitored and compared to the uncut control (OGC) over time.

Prescription Targets and Tree Marking Guidelines

We used ranges of structural attributes in the old-growth definitions to develop the old-growth maintenance prescription and tree marking guidelines for OGA and OGB. We selected 14–18 square meters of basal area per hectare (60–80 square feet per acre) as our target residual density level to significantly reduce competition and improve old-growth tree resistance to bark beetles (Table 2). This basal area target also maintains enough large trees on site to qualify as old-growth habitat. At least 25 trees per hectare ≥53.0 centimeters DBH (10 trees per acre ≥21.0 inches) are required to qualify as old-growth habitat on this plant association (USDA Forest Service 1992*b*).

Most of the target residual basal area (14–18 square meters per hectare) was allocated to the large-diameter, old-growth ponderosa pine, and to western larch. Although western larch was scarce and, in general, of poor quality, we left as much "functional" western larch as possible for diversity and to serve as a seed source. Some large-diameter Douglas-fir and grand fir were also left to maintain their historic presence. Generally, we marked large trees ≥53.0 centimeters for removal if their vigor was poor, judging from the amount of crown length (i.e., crown ratio > 30%), crown density, and needle color and length. Trees with heavy infections of mistletoe or with active bark beetle attack were also removed. We removed a large tree only if it freed up growing space for >2 large trees nearby. In some cases, large trees with poor vigor were left to augment and replace snags. Old-growth trees with lean, internal decay or other "imperfections" were left as long as they appeared vigorous, contributed to the old-growth structure, and had a high likelihood of remaining alive for several decades. Trees in the midstory layer marked for retention favored ponderosa pine and western larch over Douglas-fir and grand fir. If midstory ponderosa pine and western larch 30.0–51.0 centimeters DBH were absent, healthy Douglas-fir and some grand fir were marked for retention.

Our guidelines called for removing a heavy proportion of Douglas-fir and grand fir in the mid- and understory canopies. Patches of small-diameter ponderosa pine 10.0–20.0 centimeters DBH were to be thinned to improve growth and resistance to bark beetles and to serve as eventual replacement trees. Although OGA and OGB were marked with this prescription, only OGB was thinned. OGA became tied up in the "Eastside Screens," and was removed from harvest. Eastside Screens limit or prevent timber harvesting in riparian and late-successional forests in watersheds below their historic range of variability, and further restrict harvesting of trees ≥53.0 centimeters DBH (USDA Forest Service, Region 6, 1993).

Thinning of OGB occurred in the fall and early winter of 1993. Because slopes were generally >30%, trees were hand-felled and logs cable-yarded to a roadside landing. Cable corridors were pre-selected. The logging operator used a locking skyline carriage with lateral yarding capability, which helped to keep residual stand damage low (although some basal scars and damage to the upper boles were observed). Freshly cut stumps of ponderosa pine were treated with borax to prevent spread of annosus root rot (*Heterobasidion annosum*) to the residual old-growth trees.

In September 1994, the Prairie City Ranger District fire crews conducted an operational underburn in OGB to reduce the fuels created from the thinning slash and to kill young sapling-sized Douglas-fir and grand fir.

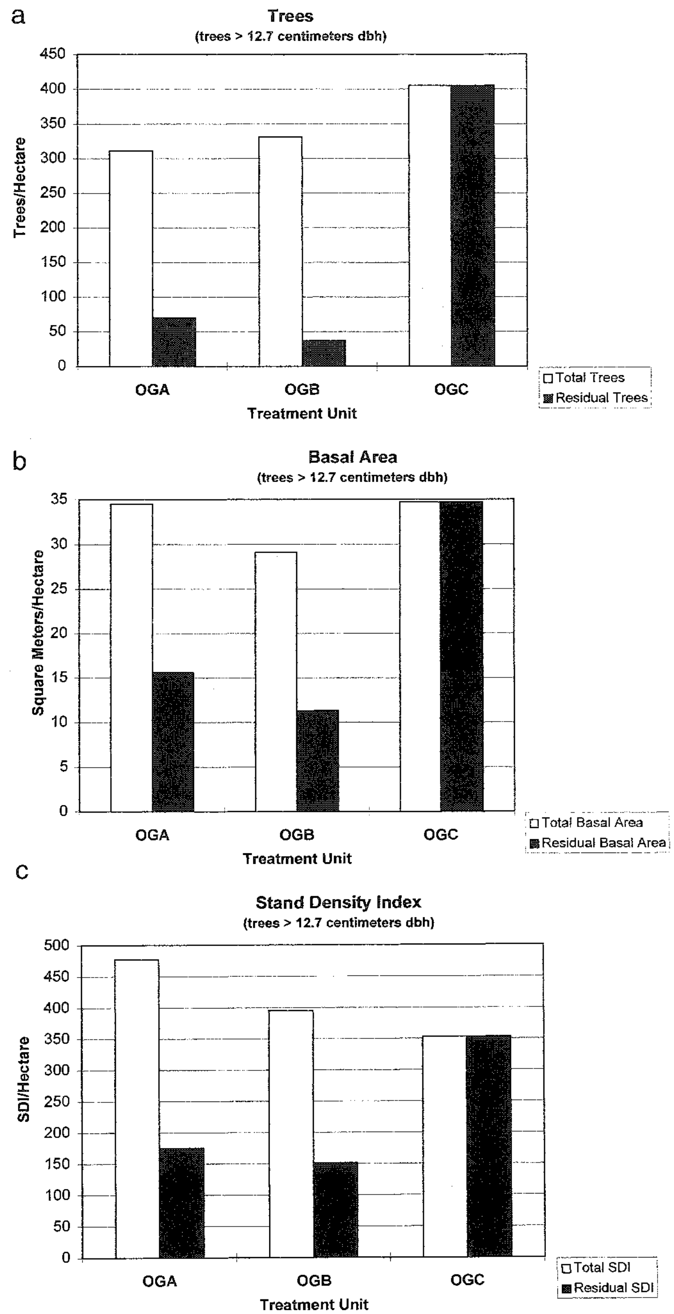

Fig. 2. Bar graphs of trees per hectare, basal area per hectare, and SDI before and after treatment for trees >12.7 centimeters DBH for OGA, OGB, and OGC. Since OGA was not treated, we show what was marked and would have been removed.

PRELIMINARY RESULTS AND OBSERVATIONS

As expected, the thinning treatment greatly reduced trees and basal area per hectare and SDI in OGB (trees >12.7 centimeters DBH) as shown in Figure 2a-c. Although the thinning did not take place in OGA, we show what was marked and would have been removed in OGA had the thinning occurred.

The trees marked for removal in OGA reduced trees per hectare from 328 to 66 (126 to 26 trees per acre) and the thinning operation in OGB reduced trees per hectare from 343 to 38 (135 to 15 trees per acre), an 80% and 89% reduction, respectively. Trees marked for removal in OGA reduced the basal area from 35 to 16 square meters per hectare (155 to 70 square feet per acre), a 55% reduction. The thinning in OGB reduced the basal area by 61% from 30 to 12 square meters per hectare (131 to 51 square feet per acre),

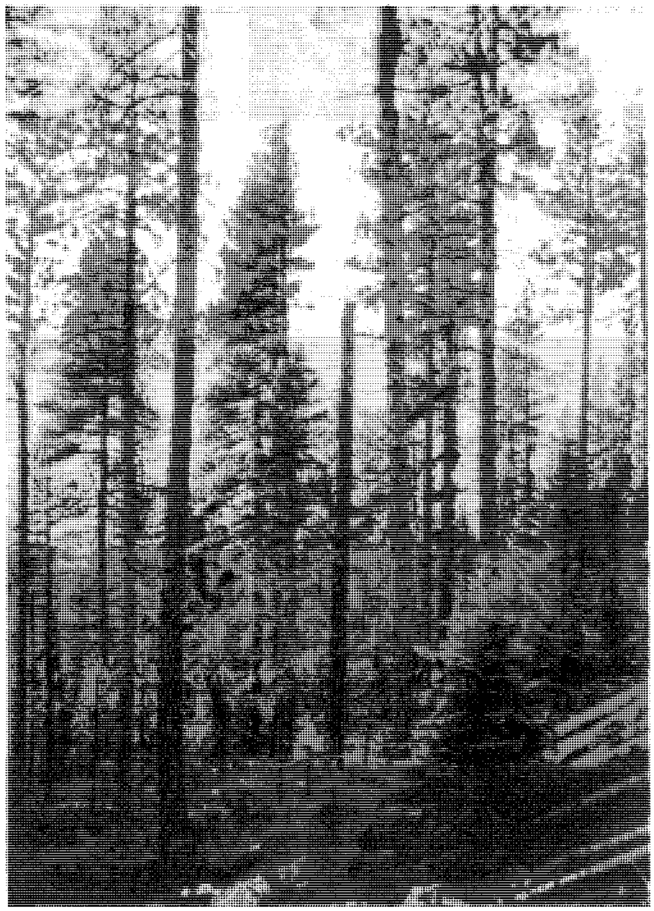

Fig. 3. Harvesting of an old-growth stand (OGB) and the residual stand structure in the Malheur National Forest, OR. Note the snag that was retained.

which was below our target basal area (Table 2). SDI of trees >12.7 centimeters was reduced from 477 to 175 in OGA and from 395 to 151 in OGB, representing a 63% and 62% reduction in site occupancy, respectively. At these lower SDI levels, enough growing space is provided for (1) the large trees to respond and remain resistant to bark beetle attack for several decades, and (2) for ponderosa pine to regenerate (Cochran 1992).

The thinning in OGB significantly changed the composition and structure of the stand (Figure 3). Stand structure changed from a dense multi-layer forest dominated by Douglas-fir and grand fir, to a much more open 2-layer forest dominated by large-diameter ponderosa pine resembling the historic stand structure and condition. Snags and large downed logs are still present.

Growth response of the residual old-growth trees in OGB since time of treatment is being evaluated using a shigometer, which measures cambial electrical resistance (CER) (Shortle et al. 1977). Preliminary results after 3 years of measurement indicate that vigor of residual old-growth trees, as measured by CER, appears to be increasing as stand density is reduced. Large, overstory ponderosa pine have demonstrated increased diameter growth following understory removals (Barrett 1969). Because tree density in OGB was reduced significantly, resulting in less inter-tree competition, the large, old-growth trees with good crowns are expected to show a diameter-growth response.

The intensity of the prescribed underburned conducted by district personnel was highly variable. In places where the tree canopy was more open and the fuels dry, the fire burned with greater intensity, killing many Douglas-fir and grand fir saplings. In some cases, a few old ponderosa pine were killed. In areas with a dense canopy or minimal fuels, the fire did not carry; understory Douglas-fir and grand fir survived. Follow-up with a chainsaw or possibly another prescribed fire will be needed to remove the Douglas-fir and grand fir understory. The underburn also consumed some existing snags and large downed logs, raising questions about whether these structures can be maintained in stands where fire will most likely play an increasing role in the future. On the other hand, the underburn also killed a few large ponderosa pine and stressed others, which will eventually die and replace snags that were consumed.

Although residual fuel loading after treatment has not been quantified, the thinning of OGB removed nearly all fuel ladders and reduced crown and canopy density. The underburn consumed most of the slash created by the thinning activity. Thus, the potential for a stand-replacing fire has been greatly reduced. To better "fireproof" OGB, surrounding stands need to be treated in a similar fashion.

As a result of the thinning and underburning, gaps and openings were created in the stand. These gaps will provide space for regeneration establishment and understory development. The Prairie City Ranger District will plant a new cohort of ponderosa pine seedlings in these openings.

SUMMARY

This case study demonstrates a silvicultural technique and process for enhancing vigor of old-growth trees after several decades of fire exclusion and increasing competition. It is too soon to conclude whether the thinning operation will enhance vigor of residual old-growth trees. Although preliminary results look promising, questions still remain about whether intervention was too late to reverse the declining vigor and condition of the old-growth trees. Vigor and response to thinning are at least partially a function of such individual tree characteristics as crown ratio and density and presence of insects and other pests.

We believe that old-growth stands today on similar sites across the interior West face elevated hazards from insects, disease, and stand-replacing fire. Forest scientists now have a much clearer understanding of fire patterns and their influence on forest succession, density, and composition and structure in the dry forested areas of the interior West. We know that sites have a fixed quantity of resources and growing space; we know that as trees get large and compete and when other trees invade and intensify inter-tree competition, trees die—and it is usually the big trees that die first (Dolph et al. 1995). We know that many existing old-growth stands are at their upper density limit, or carrying capacity. We also know that some insects, primarily bark beetles, are aggressive and seek trees under stress when density thresholds are exceeded. Thus, we believe there is an urgent need to reduce this risk in order to maintain existing old-growth patches on the landscape for the long term.

This case study demonstrates only 1 aspect of managing old-growth forests: the maintenance of existing old-growth patches. A long-term old-growth management strategy should take a landscape approach, define how much old growth is necessary or desirable, and promote and, perhaps, accelerate the development of old-growth characteristics in younger stands to provide "replacement" old growth in a shorter period of time.

Finally, land managers, stakeholders, and the general public must realize that landscapes in the interior West are dynamic, with different disturbance regimes acting at various spatial and temporal scales. Therefore, in a dynamic landscape some old-growth patches go out of existence, and others come in. Any long-term old-growth management strategy should consider and plan for these disturbance patterns, rather than drawing a line around them in an effort to preserve or "save" specific old-growth patches (Everett et al. 1994).

LITERATURE CITED

Adams, D.L. 1995. The forests of the Inland West. Pages 11–14 *in* Proceedings of forest health and fire danger in Inland Western forests held in Spokane, Washington, September 8–9, 1994. Harmon Press, n.p.

Allen, R. 1993. Administration policies and old-growth: an interview with assistant Secretary of Agriculture, James R. Lyons. Journal of Forestry 91:20–23.

Arno, S.F. 1976. The historical role of fire on the Bitterroot National Forests. Research Paper INT-187, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Arno, S.F. 1980. Forest fire history in the Northern Rockies. Journal of Forestry 78:460–465.

Barrett, J.W. 1969. Crop-tree thinning of ponderosa pine in the Pacific Northwest. Research Note PNW-100, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Barrett, S.W., S.F. Arno, and J.P. Menakis. 1997. Fire episodes in the Inland Northwest (1540–1940) based on fire history data. General Technical Report INT-GTR-370, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Bork, J. 1985. Fire history in three vegetation types on the eastern side of the Oregon Cascades. Ph.D. Dissertation. Oregon State University, Corvallis.

Brown, J.K. 1974. Handbook for inventorying downed woody material. General Technical Report INT-16, U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Cochran, P.H. 1992. Stocking levels and underlying assumptions for uneven-aged ponderosa pine stands. Research Note PNW-RN-509, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Cochran, P.H., J.M. Geist, D.L. Clemens, R.R. Clausnitzer, and D.C. Powell. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Research Note PNW-RN-513, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Covington, W.W., and M.M. Moore. 1992. Postsettlement changes in natural fire regimes: implications for restoration of old-growth ponderosa pine forests: Pages 81–99 *in* M.R. Kaufmann, W.H. Moir, and R.L Bassett (eds.). Old-growth forests in the Southwest and Rocky Mountain regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Covington, W.W., and M.M. Moore. 1994. Post-settlement changes in natural fire regimes and forest structure: ecological restoration of old-growth ponderosa pine forests. Journal of Sustainable Forestry 2:153–181.

Covington, W.W., P.Z. Fulé, M.M. Moore, S.C. Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, and M.R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry 95:23–29.

Dolph, L.K., R.R. Mori, and W.W. Oliver. 1995. Long-term response of old-growth stands to varying levels of partial cutting in the eastside pine type. Western Journal of Applied Forestry 10: 101–108.

Everett, R., P. Hessburg, J. Lehmkul, M. Jensen, and P. Bourgeron. 1994. Old forests in dynamic landscapes. Journal of Forestry 92: 22–25.

Franklin, J.F., K. Cromack, Jr., W. Denison, A. McKee, C. Maser, J. Sedell, F. Swanson, and G. Juday. 1981. Ecological characteristics of old-growth Douglas-fir forests. General Technical Report PNW-118, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Hall, F.C. 1973. Plant communities of the Blue Mountains of eastern Oregon and southeastern Washington. Region 6 Area Guide 3–1, U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, OR.

Hall, F.C. 1976. Fire and vegetation in the Blue Mountains: implications for land managers. Tall Timbers Fire Ecology Conference Proceedings 1:155–170.

Hall, F.C. 1980. Fire history—Blue Mountains, Oregon. Pages 75–81 *in* M.A. Stokes and J.H. Dieterich (eds.). Proceedings of the fire history workshop. General Technical Report RM-81, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Harrington, M.G., and S.S. Sackett. 1992. Past and present fire influences on Southwestern ponderosa pine old growth. Pages 44–50 *in* M.R. Kaufmann, W.H. Moir, and R.L Bassett (eds.). Old-growth forests in the Southwest and Rocky Mountain Regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Hessburg, P.F., R.G. Mitchell, and G.M. Filip. 1993. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Pages 485–536 *in* P.F. Hessburg (compiler). Eastside forest ecosystem health assessment. Volume III: Assessment. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Johnson, C.G. 1994. Forest health in the Blue Mountains: a plant ecologist's perspective on ecosystem processes and biological diversity. General Technical Report PNW-GTR-339, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Kilgore, B. 1973. The ecological role of fire in Sierran conifer forests: its application to National Park management. Quaternary Research 3:496–513.

Lehmkuhl, J.F., P.F. Hessburg, R.D. Ottmar, M.H. Huff, R.L. Everett, E.C. Alvarado, and R.E. Vihnanek 1993. Historical and current vegetation pattern and associated changes in insect and disease hazards and fire and smoke conditions in eastern Oregon and Washington. Pages 589–718 *in* P. F. Hessburg (compiler). Eastside forest ecosystem health assessment. Volume III: Assessment. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Long, J.N., and T.J. Dean. 1986. Sapwood area of *Pinus contorta* stands as a function of mean size and density. Oecologia 68:410–412.

Mason, R.R., and B.E. Wickman. 1993. Procedures to reduce landscape hazard from insects outbreaks. Pages 19–20 *in* R.L. Everett (compiler). Eastside forest ecosystem health assessment. Volume IV: Restoration of stressed sites and processes. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Mehl, M.S. 1992. Old-growth descriptions for the major forest cover types in the Rocky Mountain region. Pages 106–120 *in* M.R. Kaufmann, W.H. Moir, and R.L Bassett (eds.). Old-growth forests in the Southwest and Rocky Mountain Regions: proceedings of a workshop. General Technical Report RM-213, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Munger, T.T. 1917. Western yellow pine in Oregon. Bulletin No. 418. U.S. Department of Agriculture, Washington, DC.

Mutch, R.W., S.F. Arno, J.K. Brown, C.E. Carlson, R.D. Ottmar, and J.L. Peterson. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. General Technical Report PNW-GTR-310, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

O'Hara, K.L. 1996. Dynamics and stocking-level relationships of multi-aged ponderosa pine stands. Forest Science Monograph 33.

Quigley, T.M., and S.J. Arbelbide (technical editors). 1996. An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins. 2 volumes. General Technical Report, U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station, Portland, OR.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research. 46:627–638.

Scientific Society Panel. 1993. Interim protection for late-successional forests, fisheries, and watersheds. Executive summary. Scientific Society Panel, Washington, DC.

Shortle, W.S., A.L. Shigo, P. Berry, and J. Abusamra. 1977. Electrical resistance in tree cambium zone: relationship to rates of growth and wound closure. Forest Science 23:326–329.

Soeriaatmadja, R.E. 1966. Fire history of the ponderosa pine forests of the Warm Springs Indian Reservation, Oregon. Ph.D. Dissertation. Oregon State University, Corvallis.

USDA Forest Service. 1992*a*. Decision notice finding of no significant impact and environmental assessment for the Genesis Demonstration Project. Prairie City Ranger District, Malheur National Forest. Prairie City, OR.

USDA Forest Service. 1992*b*. Interim old-growth definitions for Douglas-fir, grand fir/white fir, interior Douglas-fir, lodgepole pine, Port-Orford cedar/tanoak (redwood), subalpine fir and western hemlock series. U.S. Department of Agriculture, Forest Service, Region 6, Portland, OR.

USDA Forest Service, Region 6. 1993. Decision notice for the continuation of interim direction establishing riparian, ecosystem, and wildlife standards for timber sales. U.S. Department of Agriculture, Forest Service, Region 6, Portland, OR.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry 41:7–15.

Weaver, H. 1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. Journal of Forestry 57:15–20.

Wickman, B.E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. General Technical Report PNW-GTR-295, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.