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Synthesis, part of a Special Feature on The Conservation and Restoration of Old Growth in Frequent-fire Forests of the American West

Managing for Old Growth in Frequent-fire Landscapes

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ABSTRACT. There is no one-size-fits-all approach to managing frequent-fire, old-growth forests. However, there are general guidelines to follow: 1) set objectives for both structure (tree density, diameter distribution, tree species composition, spatial arrangement, amount of coarse woody debris) and function (nutrient cycling, desired tree species regeneration); 2) prioritize treatments according to ecological, economic, and social needs and risks; 3) identify the potential treatments (natural fire, prescribed fire, silvicultural cutting) that best meet the objectives and scale of the project; and 4) implement the treatment (s). We discuss each of these guidelines in this article.

Key Words: *fire, forest management, function, silvicultural treatments, structure, thinning*

ESTABLISHING A FRAMEWORK FOR OLD-GROWTH MANAGEMENT

In their article in this special issue, Kaufmann and his colleagues (2007) point out the difficulty of defining the elusive term "old growth." However, examining multiple definitions reveals some common themes, including the importance of structure, function, and associated disturbance regime. For example, management treatments proposed for old growth in landscapes visited only every several centuries by stand-replacing fire are generally viewed as unacceptable, yet treatments may be critical for restoring structures or processes in forests historically influenced by fire every few years or decades. It is these frequent-fire-dependent forests that we will focus on in this article.

Ownership and management goals also define the range of treatments that may be compatible for restoring old-growth structures or processes. For example, treatments appropriate for designated wilderness, national parks, national monuments, and roadless areas are typically limited to natural or prescribed fire, whereas silvicultural cutting is a common treatment on private, state, and tribal ownerships, and on lands managed under conservation easements. Forests with old-growth structure largely intact, but with altered processes, will likely require a different suite of treatments than forests lacking essentially all old-growth structural components. In this article, we propose a variety of treatment approaches appropriate for a range of ownership goals and old-growth restoration needs.

SETTING OBJECTIVES FOR TREATMENT

When issues threatening sustainability have been identified in old-growth areas relative to ownership objectives, managers need to consider treatments that develop or maintain old-growth conditions. Several key attributes provide focus for managers as they set objectives for treatment. These attributes can be classified as either structural or functional.

Structural Attributes

Structural features are perhaps the most significant and observable characteristic of old-growth conditions. Although structural features alone do not old growth make, large old trees and modest amounts of large dead material (standing or downed) are essential components of old growth. Features such as stand density, diameter distribution, age distribution, species composition, and spatial arrangement provide managers with

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ranges of conditions as targets for treatment, and with benchmarks for assessing progress following treatments. Although the primary objective of managing for old growth may be ecological or visual, structural objectives, such as numbers and patterns of old trees or ranges of other structural components (e.g., reserve basal area densities or diameter distributions), typically provide more immediate and measurable treatment goals.

Density

High stand density (basal area) might seem an obvious characteristic of old growth. However, it is not a hallmark of uneven-aged, old-growth stands adapted to frequent, low-intensity disturbance. Such stands are primarily composed of shade-intolerant pines that require the creation of scattered openings every one to several decades to regenerate a new age class. The young pines need nearly full light to develop through the vulnerable juvenile stage and ultimately grow to large size. Establishing ranges of density as an objective of treatment ensures that such conditions will be created in parts of the stand during a given treatment entry. One approach is to set a reserve basal area density as a general target for the post-treatment stand. For example, a post-treatment basal area of 10–18 m^2 per hectare may provide the conditions for regeneration in parts of the stand, while reducing the density around larger trees to enhance their growth and vigor. The actual density on any given acre within a stand will typically vary considerably from the overall target or average, ranging from small openings in some parts of the stand to occasional high-density patches in others (Fiedler 1996). Most to all large, old trees are retained under this approach, with some trees retained in all diameter classes, if available, until the average target basal area for the stand is reached.

Another approach is to reserve all trees that established before about 1880 (i.e., presettlement trees) and reserve additional post-settlement trees based on lingering evidence of presettlement snags and stumps. Under this approach, a certain ratio of post-settlement trees, often ranging from 1.5 to 6 depending on tree size and intensity of the thinning prescription, is retained proximate to evidence of each presettlement tree (Friederici 2003). A hallmark of this approach is that the retained trees approximate the spatial arrangement of the historical stand.

Diameter distribution

Historical stands ranged from those dominated by large, old trees of approximately the same size to those that supported a wide range of tree sizes, including saplings, poles, and medium-sized and very large trees (Woolsey 1911, Anderson 1933, Meyer 1934, Cooper 1960). Treatments aimed at maintaining or developing large-tree-dominated structures will retain most or all of the large trees in the existing stand. Treatments on federal lands typically reserve all (or nearly all) large trees, whereas treatments applied to private, state, or tribal lands may remove a portion of the larger trees to achieve a range of objectives, including economic ones. If smaller trees or trees of other species are numerous, nearly all will be removed other than the few needed as large-tree recruits for the future. An approximate target reserve density can be specified for stands where a range of diameters is appropriate. Most of that density will be reserved as large trees, with modest amounts of basal area allocated to trees across the full range of diameters, if available (including small trees of the desired species), until the overall target density is reached.

Species composition

Old-growth stands occurring on sites classified within the frequent-fire regime were historically dominated by ponderosa pine (*Pinus ponderosa* var. *ponderosa*). The primary compositional target should also contain ponderosa pine when managing for old growth because of its adaptation to frequent, low-intensity disturbances. Ponderosa pine is also more resistant to insects and disease than its more shade-tolerant competitors (e.g., Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) or true firs (*Abies* spp.)), if present.

Spatial arrangement

Historical old-growth stands were characterized by clumpy to random spatial arrangement (Cooper 1961, Morgan et al. 2002), whereas old trees in dry savanna conditions typically occurred in random arrangement. Clumpiness may have resulted from regeneration in microsites especially hospitable to seedling establishment, such as protected areas behind downed logs, recently burned patches, or small openings created by beetle-, lightning-, or windthrow-caused deaths of one or several trees (Weaver 1951). Clumpy to random tree arrangement should also guide the marking of prescriptions focused on restoring or maintaining old-growth structures.

Coarse woody debris/snags

Large dead trees (snags) and downed logs are integral parts of old-growth structure. Although no specific historical data are available related to snags or large dead and downed pieces, researchers have deduced that frequent, low-intensity fires likely kept these features at low levels. Anecdotal evidence from historical photographs of old-growth stands show few snags or downed logs. However, large dead wood, whether standing or down, provides important habitat for certain wildlife species and invertebrates, so at least some of these features per hectare should be maintained or developed in prescriptions focused on restoring old-growth structures.

Functional Attributes

The processes associated with historical old-growth forests are less evident but, perhaps, even more important than the structures themselves. Decades to more than a century without fire have allowed historically open, old-growth structures to fill in with small- and medium-sized (often late-successional) trees. Lack of disturbance (i.e., fire) combined with high tree density have drastically slowed nitrogen cycling processes, halted formation and subsequent addition of charcoal to the soil, reduced or eliminated many disturbance-dependent and light-requiring native understory plants, and virtually halted regeneration and reasonable juvenile growth of ponderosa pine. Collectively, these changes diminish or negate the processes that characterize and sustain old-growth forests.

Nutrient cycling

Research in ponderosa pine forests shows that late-successional conditions slow nutrient cycling, particularly of nitrogen (MacKenzie et al. 2004). Studies by Covington and Sackett (1984) and Kaye and Hart (1998) in Arizona, DeLuca and Zouhar (2000) and Gundale et al. (2005) in Montana, and Wienk et al. (2004) in South Dakota show increased nutrient cycling following burning treatments compared with untreated controls, although nutrient cycling processes following a sustained, long-term burning regime are not known (Hart et al. 2005).

Ponderosa pine regeneration

The dense conditions that characterize many present-day old-growth stands preclude regeneration of a new age class of ponderosa pine that is needed to provide old-growth recruits for the future. Given that historical old-growth stands were broadly uneven aged (Meyer 1934, Weaver 1951), periodic regeneration is essential to sustain them. A detailed regeneration study in old-growth ponderosa pine stands in Montana found virtually no vigorous pine regeneration established during a 15-year period in untreated areas, whereas numerous pine seedlings established in areas that received selection cutting or selection cutting plus prescribed burning restoration treatments (Fiedler 2000). Treated stands that do not result in some pine regeneration within a decade or two suggest that silvicultural cutting or burning treatments did not adequately reduce overstory density.

Understory species diversity

Diverse understory communities in historical old-growth forests reflect the availability of light, moisture, and nutrients associated with open forest conditions and frequent surface fires. As canopies gradually close in the absence of disturbance, native understory species that require high light conditions or disturbances to germinate or sprout either gradually diminish in vigor or disappear. Studies of understory plant communities in South Dakota (Wienk et al. 2004) and Montana (Fiedler et al. 2006, Metlen and Fiedler 2006) show increased overall richness and increased numbers of native species following restoration treatments compared with untreated controls.

TREATMENT PRIORITIZATION

The maintenance and restoration of healthy old-growth stands is seldom the only goal of forest management. As a result, the conservation, restoration, and development of old growth must be balanced with other needs, and managers must consider legal land status, economics, social preferences, wildfire hazard, and proximity to human communities when establishing treatment priorities. Such decisions must be made on a site-by-site basis and are beyond the purview of this article. Here, we discuss how to prioritize treatments to perpetuate existing old growth and develop additional old-growth areas.

The first step in prioritizing treatments is to classify current forest conditions into one of three categories: 1) forests that currently feature old-growth structural components, 2) forests with developing old-growth structural components, or 3) forests lacking old-growth structural components.

Because old trees and old-growth conditions are rare in most frequent-fire forests of western North America, it is imperative to conserve and manage them where they exist. For that reason, many managers will focus their limited resources on managing Category 1 areas—existing old growth. However, it is also important to prepare some areas as future old growth. To do so, a holistic management approach on some properties will include treatments in Category 2 and Category 3 areas where development of future old growth can be accelerated through thoughtful treatments.

Although forest tracts seldom fall entirely into only one of these categories, the guidelines below provide ideas for prioritizing treatments within each category. In reality, managers should consider guidelines from all three categories for any treatment.

Category 1

Where old-growth structural components exist, several important questions should be addressed:

What is the biological and conservation value? Old-growth stands and old trees have a variety of values. Sites with extraordinarily old or large trees, or with particularly high wildlife or aesthetic value, will often merit particular consideration for treatment.

What is the risk of treatment? Restoration treatments can themselves damage old-growth stands through mechanical damage or damage from prescribed fire, and these risks must be taken into account.

What is the risk of doing nothing? Two old-growth stands with similar value may be at very different levels of risk. For example, a stand isolated on a rocky mesa may be at much lower fire risk than one surrounded by dense forest, or one stand may be much more heavily invaded by young trees than another.

What is the feasibility of treatment? Many of the stands with greatest old-growth value exist today because in the past they were too inaccessible or too steep to log. Mechanical treatments may be severely limited in steep terrain if needed to remove dense sapling/pole understories or shade-tolerant firs. Prescribed fire or wildland fire use is also limited on steep slopes due to the undesirable “chimney” effect that allows surface fires to torch into the overstory.

Category 2

Where old-growth structural components are developing, it is useful to consider the previous criteria, as well as several others:

What is the landscape setting? In treating areas currently lacking developed old-growth features, managers are essentially deciding where to accelerate the development of future old-growth conditions. It is helpful to consider the overall landscape matrix in this process: Where will old-growth conditions be most useful to wildlife and people? Conservation biology provides tools that can help assess what landscape habitat conditions are important for healthy wildlife and plant populations. For example, it may be beneficial to species such as the Mexican spotted owl (*Strix occidentalis lucida*) to establish future old-growth conditions in an area connecting two existing old-growth tracts, or it may be useful to develop old-growth conditions in remote or roadless areas that offer the opportunity for management using natural (lightning-ignited) fire.

How can overall effectiveness be maximized? Some areas are treated more easily than others, and it should be part of every prioritization exercise to consider whether to maximize treated acreage or to focus on particular high-value tracts that may be more expensive to treat.

Category 3

Extensive acreages of western pine forests lack any old-growth conditions, and restoration treatments carried out within them must take the long view. The previous questions, as well as those listed below, should be considered when prioritizing treatments in these areas.

What temporal scale should be considered? Managers treating Category 3 areas are working to establish old-growth conditions at some future time. By conducting treatments in different places and times across the landscape, managers can ensure that a mosaic of forest conditions will exist across the landscape in the future.

What can be gained through protection of adjacent areas? Forest tracts do not exist in isolation. Some of the most effective means of protecting existing old-growth stands include thinning and prescribed burning in adjacent Category 2 and Category 3 areas, especially those that are situated upwind or are topographically lower. Such treatments can help protect existing old growth from unnaturally intense disturbances and accelerate development of old-growth conditions in the surrounding treated areas.

What future maintenance will be required? Because treatments are expensive and often difficult to implement, long-term benefits can be gained by placing them across the landscape in ways that minimize the cost of future maintenance (additional thinning or prescribed burning). Conducting thinning or prescribed burning treatments in locations that maximize the acreage potentially treatable with natural fire is one example of this strategy.

Prioritizing Beyond Categories

Decisions to prioritize treatment areas are not made in isolation. In most settings, managers will have to consider treating areas that contain at least some acreage in each of the three categories, and they will have to decide how to allocate resources among those tracts. Addressing the questions posed above will help in this allocation process. Spatial assessment tools, such as those used in the ForestERA Project (www.forestera.nau.edu), can provide additional help. Qualitative assessments should also be considered. As other authors in this special issue have pointed out, the definition (and appreciation) of old growth for many observers involves primarily aesthetic and intangible considerations. As a result, it may make sense to prioritize treatments to protect or enhance old-growth qualities in a certain area simply because it is valuable to a community.

Overall stand health and tree vigor are also important considerations in deciding treatment priorities. For example, among Category 1 areas, stands composed of old trees with declining vigor would generally receive higher priority for treatment than those with vigorous old trees. In contrast, only stands comprised of vigorous middle-aged and maturing trees would be candidates for treatment in categories 2 and 3.

MANAGEMENT TREATMENTS

Management treatments may be needed, depending on current conditions, to maintain or develop old-growth conditions. Treatments can reduce stand density, remove infected trees, promote ponderosa pine regeneration, reduce fuel hazards, and alter tree spatial distribution, structure, and species composition. One or more of these modifications or effects are needed in many old-growth areas because the absence of low-intensity fire has diminished their capacity to withstand more intense fires. Likewise, treatments may be needed outside these areas to help protect them from the increasing risk of unnatural disturbances. Treatments may vary from silvicultural cutting treatments to prescribed or natural fire, used singly or in combination. However, even with these treatments, not all old-growth areas can be perpetuated indefinitely. An area may lose its old-growth characteristics through time if the old trees die and are not replaced by mature recruits. Additionally, it is inevitable that some areas will be lost through disturbance agents or events such as insects, disease, or wildfire, whether previously treated or not.

Natural and Prescribed Fire

Fire is a natural and key component of old-growth in frequent-fire forested ecosystems and is necessary for their health and sustainability. However, use of natural (lightning-ignited) fire will be severely limited in most old-growth areas until existing fuel loads are substantially reduced. Once old-growth structures are reasonably restored, natural fire can be a primary tool for maintaining these characteristics in some areas. Fire, whether natural or prescribed, may be the only treatment allowed or available in wilderness areas and national parks. Paradoxically, the manager has less control using fire than when applying cutting treatments, yet fire has unique benefits. Prescribed burning in inaccessible terrain also presents special challenges and risks, but it can be accomplished with careful planning and execution.

Prescribed burning may be the only restoration treatment applied in some old-growth areas, either because of administrative constraints on cutting or because of desired treatment effects, such as minimizing soil disturbance. More commonly, prescribed burning will be conducted as a follow-up to silvicultural cutting to reduce natural fuels plus those generated by the harvest activity. In isolated situations, carefully applied prescribed burning may be needed before silvicultural cutting to reduce existing fuels before even more fuels are created in the form of slash. Even after cutting, careful burning is necessary to reduce damage to leave trees, particularly if slash is left within the stand. Raking thick duff layers away from the base of old trees may be beneficial in some situations to reduce mortality from prescribed burning (Covington et al. 1997).

Intermediate Treatments

Intermediate cutting treatments that modify stand density, structure, or species composition may be necessary to develop or maintain old-growth characteristics in some areas. Intermediate treatments have moderate-level, short- to mid-term effects intended to move conditions closer to the long-term old-growth goal. Thinning, improvement cutting, and sanitation cutting are examples of intermediate treatments commonly applied in restoration prescriptions to make mid-course corrections in stand density, species composition, or health and vigor. Their purpose is not to secure regeneration. Subsequent intermediate treatments will likely be less frequent and invasive than those applied initially to maintain or develop old-growth structures. However, multiple treatment entries over decades or centuries may be needed to maintain or develop old-growth conditions.

Thinning

Thinning helps protect old-growth areas invaded by younger trees from damage by fire or insects. It also reduces competition for limited resources, thereby improving the vigor and growth of remaining trees. Most old-growth areas adapted to frequent fire cannot be maintained without some form of thinning, whether by fire or silvicultural cutting.

Improvement cutting

This intermediate treatment is aimed at manipulating species composition, improving overall tree form and quality, and increasing vigor. The most common application in old-growth stands is to remove shade-tolerant species (e.g., Douglas-fir and true firs) that are generally more vulnerable to insects, disease, and fire.

Sanitation cutting

Once areas meet structural and compositional goals, periodic treatments may be needed to maintain overall stand health and perpetuate old-growth characteristics. Sanitation cutting is aimed at removing insect-infested (e.g., bark beetles (*Dendroctonus* spp.)) or diseased (e.g., dwarf mistletoe (*Arceuthobium* spp.) trees that pose an immediate threat to surrounding trees.

Regeneration Treatments

Regeneration treatments are conducted to establish a new age class of trees in a stand. Many old-growth areas have not had successful ponderosa pine regeneration for decades. Regeneration cuttings are needed in some of these areas to recruit young trees that will develop into large-tree recruits in the distant future. A short-term reduction in the quality of old growth resulting from regeneration cutting may be the trade-off for higher-quality old-growth characteristics in the future, with much-extended life expectancy.

Traditional uneven-aged regeneration methods, such as individual tree or group selection cuttings, need to be modified in various ways to promote old-growth conditions. Customized selection cuttings have been designed and implemented to develop or restore old-growth in Montana (Fiedler 2000, Arno and Fiedler 2005). These modified approaches to selection cutting are not aimed at regulating growth and yield in the traditional sense, but focus instead on developing and perpetuating uneven-aged conditions that include a primary component of large, old trees. Reserve basal areas of 10–18 m^2 per hectare are prescribed for post-treatment stands. Densities at the high end of this range are retained in stands dominated by large trees, as significantly lower resource use is associated with a square meter of basal area in larger trees than in smaller ones (Fiedler and Cully 1995). Virtually all of the large, old pines are retained, as well as healthy ponderosa pines across the full range of diameters, if available, until the target density is achieved. The post-treatment stand exhibits high vertical and horizontal diversity, ranging from occasional patchy openings to variably spaced trees of different sizes to clumps of larger trees. A primary treatment objective is to regenerate a new age class of pine in scattered patches throughout the stand, with the long-term goal of perpetuating old-growth conditions in place, over time. Although modified selection cutting approaches are based on a combination of silvicultural and ecological factors, treated stands bear some resemblance to ecological restoration treatments based on numbers and locations of pre-European settlement trees (Friederici 2003).

Staged Treatments

Clearly identified objectives are fundamental to determining the type(s) of treatments needed within designated old-growth areas. These objectives should identify both short- and long-term needs. High on the list of immediate needs would be to address existing threats, such as insects, disease, wildfire, and human encroachment.

Although protective treatments may be essential in the short term, longer-term strategies for moving old-growth areas toward healthy and sustainable conditions are also needed. Such activities may need to be staged over long periods of time, depending on existing conditions and their degree of departure from desired conditions. Treatments to reduce immediate threats could entail one or several intermediate treatments, such as thinning or improvement cutting to alter tree density and species composition, or sanitation cutting to remove infected trees that threaten surrounding trees. These activities may temporarily diminish old-growth attributes, but greatly improve quality and sustainability over the long term.

Scale of Treatment

The size of an existing or a desired old-growth area is an important factor in determining what treatment (s) might be used to achieve desired results. Old-growth areas range in size from landscapes to stands, and in some cases, even sub-stands or patches. As the size of the old-growth area and associated treatment increases, so sometimes do the ecological benefits. For example, wildlife habitat for some birds and mammals—a key old-growth function—may be enhanced by landscape-scale treatments (Sisk et al. 2005). Larger areas, particularly those being developed as future old growth, can typically be treated more efficiently and economically than smaller areas.

TREATMENT IMPLEMENTATION

Prescriptions to treat old-growth forests cannot be developed or implemented based on ecological considerations alone. Other potentially influential factors include local, state, and federal policies and regulations; social acceptability; operational realities; cultural sensitivity; and economics (Cortner 2003). Implementation of restoration treatments—on federal lands in particular—will not proceed without integrating public viewpoints and concerns in project planning and prescription development.

Fire Treatments

Fire is an integral treatment or disturbance process in the restoration of old-growth forests. Just how this disturbance process is implemented largely depends on ownership and management goals. Natural fire (lightning ignited) will likely only be used on public lands and in administrative units, such as wilderness areas, that preclude other forms of management. Even in those settings, an oversight team closely monitors the size, spread, and intensity of the fire in light of current and forecast weather conditions, fuel, and terrain. The team can call for direct suppression at any time. Natural fires will likely remain a relatively little-used option for treating old-growth stands until restoration cutting treatments, particularly in Category 2 and 3 areas outside wilderness, are conducted at landscape scales.

The use of fire as a restoration treatment primarily occurs in the form of prescribed burning on public or tribal lands. Burning is used relatively little by state and private landowners because of the cost and hazard associated with its use, and because such ownerships typically occur as isolated parcels surrounded by other ownerships. The potential legal and financial penalties if a prescribed burn gets away are perceived by these landowners to far outweigh potential benefits. Where prescribed burning is used, it must be conducted under carefully monitored conditions to achieve desired treatment effects, adequately disperse smoke, and minimize chances of fire escape. Prescribed fire introduced into overgrown stands may produce effects too severe for mature trees to survive (Zimmerman 2003). Indeed, use of fire alone is risky considering the existing high fuel loads in most old-growth areas (Fulé et al. 2004). Prescribed burning in these conditions will be safer and conducted with more predictable results if preceded by mechanical fuel removal. Conversely, prescribed fire applied in an overly conservative manner may result in under-consumption of fuels, survival of undesirable understory trees, and wasted effort and expense (Zimmerman 2003).

Two burning techniques—jackpot burning and broadcast burning—are generally perceived as having positive ecological effects. Jackpot burning involves igniting concentrations of fuels on the forest floor, whether they are natural fuels or fuels resulting from a silvicultural cutting treatment (also referred to as activity fuels). Broadcast burning involves burning surface fuels across virtually the entire area under prescription. It is typically implemented using a strip head-fire technique that involves igniting strips with a drip torch along the contour of a slope, progressing from top to bottom. On flat terrain, ignition generally starts at the leeward side of the area and proceeds into the wind. Widening or narrowing the width between strips increases or decreases fire intensity, respectively.

Season of burning also differentially affects both the site and reserve trees. Spring burning is popular in some parts of the western United States because smoke dispersal is generally good, treated areas with heavy fuels can be burned more safely, soil damage is minimal because forest floor and duff materials are only partially dried, spotting is reduced because surrounding areas have “greened” up, post-burn mop-up is simpler and cheaper, and it is easier to retain coarse woody materials desired for ecological objectives. One disadvantage is that roots of old trees and crowns of all trees are especially vulnerable to damage if burning is conducted after growth has begun. Fall prescribed burning perhaps better approximates natural fire because understory vegetation has cured, so a greater proportion of the area is burned. Greater duff reduction is also achieved, which benefits regeneration of ponderosa pine. However, fall burning of the heavy fuel loads resulting from treatment is risky, and atmospheric inversions greatly limit the number of burning days because of poor smoke dispersal.

Silvicultural Cutting Treatments

Achieving restoration objectives through the use of silvicultural cutting treatments depends not only on characteristics of the treatments themselves, but also on how they are marked and implemented.

Marking the prescription

The first step in the field application of a silvicultural cutting prescription involves marking “cut” or “leave” trees. Experience in both the Inland Northwest and Southwest demonstrates the advantages of leave-tree marking: 1) it allows the marker to visualize the stand after treatment in terms of the numbers, sizes, and juxtaposition of the remaining trees, 2) it allows an exact determination of reserve stand density, because every tree designated for leave is known, 3) it generally involves marking fewer trees, particularly in the first entry, 4) it is easier to approximate the desired future stand (target stand) compared with marking cut trees, and 5) it is far less likely that a diseased tree will be missed compared with cut-tree marking.

Implementing the prescription

Silvicultural cutting in old-growth stands, whether in the form of intermediate or regeneration treatments, entails cutting some trees and leaving others. Both hand and mechanical methods are reasonable options for cutting trees. Hand-felling trees with chain saws has little effect on the site, but is more likely to damage reserve trees because of the restricted control the feller has about where trees fall. Hand felling may be the only option on fragile soils or steep terrain (i.e., slopes >40%), or in situations where some cut trees exceed the size capabilities of mechanical fellers. In contrast, use of mechanized harvesting equipment (e.g., feller-bunchers and single-grip harvesters) allows greater control over the felling and placement of trees after they are cut. These machines have a cutting head (continuous disk saw or bar saw), typically located at the end of an articulated boom. They are more efficient than hand felling, but the high cost of moving them in and out of a project area limits their use on small treatment areas. Other factors, including availability of skilled fallers or mechanized harvesting equipment, may determine which felling method is used in a given situation or locale.

Where trees are cut and used for products, two harvest methods (log length or whole tree) are commonly employed to implement treatment prescriptions. In the log-length method, trees are hand felled and bucked into logs in the woods and later transported to a landing. Alternatively, trees can be felled with a cut-to-length machine, processed into logs, and piled in the woods for later skidding/forwarding. Whole-tree methods involve felling trees (either by hand or mechanically) and skidding them intact to a landing, where they are then processed into logs. On steep terrain, trees are usually hand-felled and later transported to a landing via cable, skyline, or helicopter.

Logs may be skidded in a ground-based harvest system using four-wheel-drive farm tractors, rubber-tired grapple skidders, bulldozers, or log forwarders. Tractors and rubber-tired skidders typically cause the most equipment-related soil compaction. Both bulldozers (equipped with tracks) and log-forwarders (equipped with large, inflatable tires) dissipate pressure across a large surface area, resulting in relatively little compaction. Skidding when soils are frozen can greatly reduce both soil displacement and compaction, regardless of skidding method.

Treating the slash

Large volumes of slash accumulate in the woods or at the landing, regardless of whether some trees are removed for products or whether all trees are too small or low-value to be used. Slash in the woods is a fire hazard, visually obtrusive, suppresses growth of understory plants, and serves as a physical barrier to use by livestock and wild ungulates. Conversely, it can serve as a source of nutrients and organic matter for the soil, provide protection for tree regeneration, reduce soil erosion, and provide small mammal habitat. If slash loads are light, they can be left to decay. Heavier slash accumulations can be lopped and scattered, chipped, crushed, masticated, piled and burned, jackpot burned, or broadcast burned. Activity fuels typically require about a year to cure before burning. Pile burning effectively reduces fire hazard but has few ecological benefits, and the intense burning in localized spots can damage soils and provide hospitable substrate for invasive plant species. Jackpot and broadcast burning effectively reduce fire hazard and accelerate recycling of nutrients. Mechanical methods of treating slash (e.g., lopping and scattering, chipping) result in only very gradual decomposition because the high carbon:nitrogen ratios in wood significantly slow microbial activity and subsequent nutrient recycling.

Other Considerations

Protection of soil and water resources is essential for long-term ecosystem health. Consequently, all treatments in old-growth stands should be implemented using locally applicable best management practices. Best management practices provide flexible guidelines and site-specific options to help reduce soil erosion and protect water quality during silvicultural operations.

The types of treatments needed to develop or maintain old-growth areas, or to buffer and protect existing old growth, may not be allowed under federal environmental laws (e.g., Endangered Species Act or Clean Air Act), agency regulations, or local policies. Existing regulations or policies may need to be amended to allow treatments to occur. Additionally, local or regional socio-political issues may restrict the type or frequency of treatments. Such issues can be difficult to overcome and may be more constraining than operational, economic, or ecological factors.

Other factors, such as wildlife issues or archaeological/cultural resources, may severely restrict treatment options or rule out management altogether. Issues associated with wildlife can greatly affect the timing of treatments. Managers must be aware of seasonal issues, such as nesting season for birds and calving/fawning seasons for game species. Seasonal use by threatened and endangered species may also affect when treatments are implemented, if at all. Archaeological/cultural resources, such as Native American burial areas and habitations, old mines, and cabin foundations may restrict or preclude prescribed burning because combustible remains may be consumed (Romme et al. 1993), and non-combustible materials may experience physical or chemical change by prescribed fire. Physical damage or destruction during mechanical treatments also pose concerns (Traylor et al. 1990), so specialists from appropriate disciplines should be contacted before treatments are implemented.

CONCLUSIONS: MANAGING FOR THE FUTURE

Old-growth forests that were historically shaped by frequent surface fires now show alarming decline at several levels, including individual tree health and vigor, sometimes changing species compositions, and increased stand-level vulnerability to insects, disease, and severe fire. Management treatments have potential to ameliorate many of these problems. However, we must recognize that the old-growth "problem" has no simple or complete solution; the current "hands off" or passive management approach to this problem is not working (Agee 2002); and that active management by humans offers the greatest hope for restoring functional old-growth areas—maybe the only hope.

Old-growth areas can, perhaps, be perpetuated for decades or centuries with thoughtful management, but they may not be "permanent" on a multi-century or millennial time scale. Hence, prospective old-growth areas need to be identified and treated to develop replacements for existing areas over the longer term. Moir and Dieterich (1988) identified open, mistletoe-free pine stands with 150- to 200-year-old trees as areas with high potential for old-growth recruitment (e.g., Category 2 and 3 areas). Silvicultural cutting and prescribed burning in these areas should reduce fuels, recycle nutrients, invigorate trees and understory plants, and regenerate a new age class of pine. Treating landscapes instead of stands will further increase the functionality and ecological value of these areas over time, and increase their resiliency to disturbance and climatic change. Because old-growth pine respond to temperature and moisture conditions both during and outside the growing season (Steele and Fiedler 1996), treatments that increase tree vigor should also make existing old-growth stands more resilient to changing temperature and precipitation regimes.

Restoration at any significant scale cannot be accomplished without a supporting infrastructure, which includes people and equipment to do the work and markets for the associated wood products and waste material (Arno and Fiedler 2005). The availability of skilled workers and appropriate equipment allows treatments to be implemented as designed, with minimal negative effects on both the site and the remaining trees. A healthy and diverse infrastructure includes sawmills, pulp mills, wafer-board plants, post-and-pole plants, log home manufacturers, and specialty product makers, among others. The availability of markets for different kinds and sizes of trees reduces the amount of woody fuel that must be treated on site to reduce hazard. The presence of multiple outlets for wood products or biomass also provides revenue that can help offset treatment costs, allowing greater numbers of hectares to be treated. This is essential if treatments are to occur on most non-federal lands.

A wide array of forest conditions and management objectives exist across the federal, state, tribal, and private entities that provide stewardship of old-growth forests. The kinds of management employed by one landowner may not be appropriate for another. However, varied management approaches will yield valuable lessons and diverse examples of old-growth conditions (existing and developing) from which all ownerships can learn and adapt their management over time.

Responses to this article can be read online at:
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LITERATURE CITED

Agee, J. K. 2002. The fallacy of passive management of western forest reserves. *Conservation Biology in Practice* **3**:18–25.

Anderson, I. V. 1933. *Application of selective logging to a ponderosa pine operation in western Montana.* Bulletin No. 339. University of Montana, Missoula, Montana, USA.

Arno, S. F., and C. E. Fiedler. 2005. *Mimicking nature's fire: restoring fire-prone forests in the West.* Island Press, Washington, D.C., USA.

Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* **30**:129–164.

———. 1961. Pattern in ponderosa pine forests. *Ecology* **42**:493–499.

Cortner, H. J. 2003. The governance environment: linking science, citizens, and politics. Pages 70–80 *in* P. Friederici, editor. *Ecological restoration of southwestern ponderosa pine forests.* Island Press, Washington, D.C., USA.

Covington, W. W., and S. S. Sackett. 1984. The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in woody debris and forest floor. *Forest Science* **30**:183–192.

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. Restoration of ecosystem health in southwestern ponderosa pine forests. *Journal of Forestry* **95**:23–29.

DeLuca, T. H., and K. L. Zouhar. 2000. Effects of selection harvest and prescribed fire on the soil nitrogen status of ponderosa pine forests. *Forest Ecology and Management* **138**:263–271.

Fiedler, C. E. 1996. Silvicultural applications: restoring ecological structure and process in ponderosa pine forests. Pages 39–40 *in* C. Hardy and S. Arno, editors. *The use of fire in forest restoration.* U.S. Forest Service Rocky Mountain Forest and Range Experiment Station General Technical Report **RM-278**.

———. 2000. Restoration treatments promote growth and reduce mortality of old-growth ponderosa pine (Montana). *Ecological Restoration* **18**:117–119.

Fiedler, C. E., and J. F. Cully, Jr. 1995. A silvicultural approach to develop Mexican spotted owl habitat in southwest forests. *Western Journal of Applied Forestry* **10**:144–148.

Fiedler, C. E., K. L. Metlen, and E. K. Dodson. 2006. Restoration/fuels reduction treatments differentially affect native and exotic understory species in a ponderosa pine forest (Montana). *Ecological Restoration* **24**:44–46.

Friederici, P. 2003. The “Flagstaff model.” Pages 7–25 *in* P. Friederici, editor. *Ecological restoration of southwestern ponderosa pine forests.* Island Press, Washington, D.C., USA.

Fulé, P. Z., A. E. Cocke, T. A. Heinlein, and W. W. Covington. 2004. Effects of an intense prescribed forest fire: is it ecological restoration? *Restoration Ecology* **12**:220–230.

Gundale, M. J., T. H. DeLuca, C. E. Fiedler, P. W. Ramsey, M. G. Harrington, and J. E. Gannon. 2005. Restoration treatments in a Montana ponderosa pine forest: effects on soil physical, chemical and biological properties. *Forest Ecology and Management* **213**:25–38.

Hart, S. C., T. H. DeLuca, G. S. Newman, D. M. MacKenzie, and S. I. Boyle. 2005. Post-fire vegetative dynamics as drivers of microbial community structure and function in forest soils. *Forest Ecology and Management* **220**:166–184.

Kaufmann, M. R., D. Binkley, P. Z. Fulé, M. Johnson, S. L. Stephens, and T. W. Swetnam. 2007. Defining old growth for fire-adapted forests of the western United States. *Ecology and Society* **12**(2): 15. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art15/.

Kaye, J. P., and S. C. Hart. 1998. Ecological restoration alters nitrogen transformations in a ponderosa pine–bunchgrass ecosystem. *Ecological Applications* **8**:1052–1060.

MacKenzie, D. M., T. H. DeLuca, and A. Sala. 2004. Forest structure and organic matter analysis along a fire chronosequence in the low elevation forests of western Montana. *Forest Ecology and Management* **203**:331–343.

Metlen, K. L., and C. E. Fiedler. 2006. Restoration treatment effects on the understory of ponderosa pine/Douglas-fir forests of western Montana, USA. *Forest Ecology and Management* **222**:355–369.

Meyer, W. H. 1934. Growth in selectively cut ponderosa pine forests of the Pacific Northwest. USDA Technical Bulletin No. **407**.

Moir, W. H., and J. H. Dieterich. 1988. Old-growth ponderosa pine from succession in pine–bunchgrass forests in Arizona and New Mexico. *Natural Areas Journal* **8**:17–24.

Morgan, T. A., C. E. Fiedler, and C. W. Woodall. 2002. Characteristics of dry site old-growth ponderosa pine in the Bull Mountains of Montana, USA. *Natural Areas Journal* **22**:11–19.

Romme, W. H., L. Floyd-Hanna, and M. Connor. 1993. Effects of fire on cultural resources at Mesa Verde National Park. *Park Science* **26**:28–30.

Sisk, T. D., M. Savage, D. A. Falk, C. D. Allen, E. Muldavin, and P. McCarthy. 2005. A landscape perspective for forest restoration. *Journal of Forestry* **103**:319–320.

Steele, B., and C. Fiedler. 1996. Kalman filter analysis of growth–climate relations in old-growth ponderosa pine and Douglas-fir stands. *Radiocarbon* **38**:303–314.

Traylor, D., L. Hubbell, N. Wood, and B. Fiedler. 1990. The 1977 La Mesa Fire study: an investigation of fire and fire suppression impact on cultural resources in Bandelier National Monument. Professional Paper No. **28**. U.S. National Park Service, Southwest Cultural Resource Center.

Weaver, H. 1951. Fire as an ecological factor in southwestern ponderosa pine forests. *Journal of Forestry* **49**:93–98.

Wienk, C. L., C. H. Sieg, and G. R. McPherson. 2004. Evaluating the role of cutting treatments, fire and soil seed banks in an experimental framework in ponderosa pine forests of the Black Hills, South Dakota. *Forest Ecology and Management* **192**:375–393.

Woolsey, T. S., Jr. 1911. Western yellow pine in Arizona and New Mexico. USDA Forest Service Bulletin No. **101**. USDA Forest Service, Washington, D.C., USA.

Zimmerman, G. T. 2003. Fuels and fire behavior. Pages 126–143 *in* P. Friederici, editor. *Ecological restoration of southwestern ponderosa pine forests.* Island Press, Washington, D.C., USA.