An Ecosystem Management Strategy for Southern Sierran Mixed-Conifer Forests

North, M.[1], P. Stine[1], K. O'Hara[2], W. Zielinski[3], and S. Stephens[2]

1. U.S.F.S. Sierra Nevada Research Center, 1731 Research Park Dr., Davis, CA 95618, mpnorth@ucdavis.edu, pstine@fs.fed.us
2. Department of Environmental Science, Policy and Management, 137 Mulford Hall, University of California, Berkeley, 94720-3114, ohara@nature.berkeley.edu, stephens@nature.berkeley.edu
3. U.S.F.S. Redwood Sciences Lab, 1700 Bayview Dr., Arcata, CA 95521, bzielinski@fs.fed.us

In recent years, there has been substantial debate over how Sierra Nevada forests should be managed. All perspectives on this debate inevitably cite "sound science" as a necessary foundation for any management practice. Over the last dozen years since publication of the Sierra Nevada Ecosystem Project (SNEP 1996), many relevant research projects have published findings in dozens of scientific journals, yet these have rarely been synthesized or presented in a form that speaks directly to current land management challenges. The intent of this paper is to propose a set of management recommendations based on recent research findings and opportunities to implement new forest management practices in southern Sierran mixed-conifer forests.

Current management usually cites a "healthy forest" (http://www.fs.fed.us/projects/hfi) as a primary objective. It is difficult, however, to define forest 'health', and as a broad concept, it provides few specifics to guide management or assess forest practices. A premise of silviculture is that forest prescriptions can be tailored to fit a wide variety of land management objectives, once those objectives are defined. In this paper, we attempt to define some of the key management objectives on National Forest lands in the southern Sierra and how they might be approached through particular silvicultural prescriptions.

1. Recent Scientific Information and Its Limitations

Much of current Sierran forest management is focused on landscape strategies intended to achieve immediate fuels reduction (e.g.., Strategically Placed Area Treatments (SPLATs) (Finney 2001) and Defensible Fuel Profiles Zones (DFPZs)) (SNFPA 2004). These treatments have largely been developed with a short-term view, relying, in part, upon various diameter limits for mechanical tree removal. As the efficacy of these treatments is debated, actual fuel-treated acres are falling far behind Forest Service goals (e.g., approximately 120,000 ac/yr in the Sierra Nevada) or what some reports have suggested is necessary to reduce high-severity fire risk across the landscape (Stephens and Ruth 2005, Stephens et al. 2007a). There has been no long-term strategy for ecological restoration of forests impacted by 100 years of fire suppression and past logging practices. We have learned much in recent years, however, that can contribute to re-evaluating Sierran forest management strategies. We believe a more complete understanding of the ecological role of fire, fuel dynamics, sensitive wildlife habitat, and the importance of forest heterogeneity can help revise current land management practices.

A central premise of this paper is that the risks of carefully considered active management are lower than the risks of inaction in the Sierras' fire-prone forest types. We also recognize the need to address specific management priorities (e.g. sensitive species), while developing practical and ecologically sound silvicultural guidelines. Implementing the ideas contained within this ecosystem management strategy will be challenging and require some innovations, but may provide a greater range of management options than do current practices. Our scientific understanding of mixed-conifer ecosystems remains incomplete and therefore it is important to continue learning from these strategies as they are applied. We have tried to emphasize which information is supported by many studies, which is suggested by fewer but often recent studies, and what we can only infer from lines of evidence or observation but do not yet know with any degree of certainty.

In the following sections (2-6) we summarize recent, relevant scientific research, providing context, rationale, and citations for each section's themes. Section 7 lists research needed to improve and modify implementation. In section 8, we summarize the paper's content in short bullet points, distilling the applied management implications

2. Importance of Fire

Fire was once very common in most of the Sierra Nevada and has been a primary force shaping the structure, composition and function of mixed-conifer forests (McKelvey et al. 1996, Stephens at al. 2007a). Forest management practices of the last ~100 years have precipitated significant changes in these forests and their restoration will require flexible, innovative solutions. Fundamentally, however, management strategies need to recognize that, in many situations, fire is both a viable fuel-treatment tool (Agee and Skinner 2005) and an important jumpstart for many ecosystem processes stalled by accumulating surface fuels and the absence of frequent burn events (North 2006). Fire should play a pivotal role in reshaping and maintaining mixed-conifer ecosystems.

2a. Ecological role

The main effect of low-intensity fire is its reduction of natural and activity fuels, litter and shrub cover, all of which open growing space, provide a flush of soil nutrients, and increase the diversity of plants, and invertebrates (Murphy et al. 2006, Apigian et al. 2006, Moghaddas and Stephens 2007, Knapp et al. 2007, Wayman and North 2007). By opening the canopy, fire also increases habitat and microclimate heterogeneity at site, stand, and landscape levels (Chen et al. 1999, Concilio et al. 2006, Miller and Urban 1999, Collins et al. 2007, Falk et al. 2007, Hessburg et al 2007). Fire is an indispensable management tool, doing much of the work restoring ecological processes (Bond and van Wilgen 1996, Covington et al. 1997, Stephenson 1999, North 2006, Sugihara et al. 2006).

By itself, prescribed fire will be difficult to apply in some forests due to fuel accumulations, changes in stand structure, and operational limitations on its use. Mechanical thinning can be an effective tool to modify stand structure and influence subsequent fire severity and extent (Agee et al. 2000, Agee and Skinner 2005) and is often a required first treatment step in forests containing excessive fuels loads. Currently prescribed fire is generally implemented very carefully, killing only the smaller size classes (Kobziar et al. 2006). In many cases it is ineffective for restoring resilience, at least in the first pass (Ritchie and Skinner 2007). For example, prescribed fire may not kill many of the larger ladder fuels or co-dominant fir trees that have grown in with fire suppression (Knapp and Keeley 2006, North et al. 2007). In some stands, mechanical thinning followed by prescribed fire may be necessary to achieve stand resilience objectives much faster than prescribed fire alone. Fire should be used whenever feasible. Current policies that govern smoke emissions and severely limit fire use should be carefully re-evaluated to assess the balance of costs and benefits over several decades.

With air quality regulations, increasing wildland home construction, and limited budgets, some forests cannot be prescribed burned, at least as an initial treatment. Yet restoration of these forests still depends on modifying fuels because it reduces wildfire intensity when a fire does occur (Agee and Skinner 2005) and can produce stand conditions that simulate *some* of fire's ecological effects (Stephens and Moghaddas 2005, Innes et al. 2007, Wayman and North 2007). Controlling fuels allows fire, both wildland fire use and prescribed fire, to be more frequently used as a management tool.

2b. Fuels management

Forest fuels are usually assessed in three general categories; surface, ladder, and crown bulk density (Agee et al. 2000). Much of the focus of fuels treatment has been on ladder fuels (generally defined to be understory trees of different sizes that provide vertical continuity of fuels from the forest floor to the crowns of overstory trees (Menning and Stephens 2007, Keyes and O'Hara, 2002)). Some studies and models, however, suggest a crown fire entering a stand is rarely sustained (i.e. sustained only under extreme weather conditions) if understory fuels are too sparse to generate sufficient radiant heat (Agee and Skinner 2005, Stephens and Moghaddas 2005). Surface fuels merit as much attention as ladder fuels when stands are treated. Prescribed fire is generally the most effective tool for reducing surface fuels.

One approach to developing fuels prescriptions, similar to current Forest Service procedures, is using modeling software to understand how different fuel size loads and weather condition affect predicted fire intensity. For example, Stephens and Moghaddas (2005) have modeled fire and weather behavior using Fuels Management Analysis (FMA) (Carlton 2004) and Fire Family Plus software (Main et al. 1990), respectively. FMA uses two modules, Dead and Down Woody Inventory (data supplied by the Brown (1974) fuels inventory) and Crown Mass (data supplied by inventories of trees by species, size, height and crown ratio), to model a stand's crowning and torching index (the wind speed needed to produce an active and passive crown fire), scorch height, and tree mortality. All four outputs can be controlled by changing surface and ladder fuels giving managers an opportunity to interactively develop target fuel conditions for a desired fire behavior. Fuels are reduced until the crowning and torching index are higher than conditions that are likely to occur even under extreme weather events (e.g. Stephens and Moghaddas 2005).

In addition to ladder and surface fuels, managers have been concerned about reducing canopy bulk density. Overstory trees are removed and leave trees are evenly spaced to increase crown separation. The efficacy of crown bulk density reduction in modifying fire behavior is largely a function of weather conditions. Research has suggested there is often limited reduction in crown fire potential through overstory thinning alone, without also treating surface fuels (Agee et al. 2000, Agee and Skinner 2005). However, some field observations (JoAnn Fites Kaufmann, Forest Service Enterprise Team, Steve Eubanks, Tahoe National Forest) suggest that under severe weather conditions (e.g. sustained high winds) or on steep slopes, crown separation may reduce the risk of crown fire spread. Fire behavior under extreme conditions is still difficult to model and what constitutes 'extreme' (since many wildfires occur under hot, windy conditions) also has not been defined (for the Southwest see Crimmins 2006). In forests adjacent to homes, steep slopes, or key strategic points, managers may want to reduce canopy bulk density to reduce potential fire severity under all possible weather scenarios. Outside of those cases, the value of crown separation in preventing crown fire spread may be limited (Agee et al. 2000, Stephens and Moghaddas 2005).

A concern with the widespread use of crown bulk density thinning in defensible fuel profile zones (DFPZ) is the ecological effects of the regular tree spacing. Studies in Baja's Sierra San Pedro del Martir forests indicate forest structures (live trees, snags, logs and regeneration) are highly clustered (Stephens 2004, Stephens and Fry 2005, Stephens and Gill 2005, Stephens et al. 2007b). This forest in Mexico shares many characteristics of mixed-conifer forests found in the Sierra Nevada but has had little fire suppression. Therefore it may be a useful analog of a mixed-conifer forest with an active fire regime. In the Sierra Nevada, historical data (Lieberg 1902, Bouldin 1999), narratives (Muir 1911) and reconstruction studies

(Bonnickson and Stone 1982, Minnich et al. 1995, Barbour et al. 2002, Taylor 2004, North et al. 2007) also indicate mixed-conifer forests were highly clustered with groups of trees separated by sparsely treed or open gap conditions. This clustering can be important for regenerating shade-intolerant pine (York et al. 2003, North et al. 2004, Gray et al. 2005), increasing plant diversity and shrub cover (North et al. 2005a), and providing a variety of microhabitat conditions for birds (Purcell and Stephens 2007) and small mammals (Innes et al. 2007b, Meyer et al. 2007b). A clumped tree distribution, where groups are separated by gaps, might also slow crown fire spread, but we do not know of any studies which have examined this idea. Studies in other mixed-conifer forests (e.g. Klamath Mountains and eastern Washington) imply this heterogeneity may be an important characteristic of frequent fire's effect on mixed-conifer forests (Taylor and Skinner 2004, Hessburg et al. 2005, 2007). Fuels treatments which produce uniform leave tree spacing reduce this ecologically important spatial heterogeneity.

3. Climate Change and Process Restoration

Forest restoration has often examined past conditions, such as the pre-European period, as a basis for developing management targets. However, with climate change, is restoring forests to these conditions even an appropriate goal? Returning to a pre-European condition, a 'back to the future' approach is unlikely to be feasible because climate, grazing activities, and Native American ignitions have all changed (Millar and Woolfenden 1999, Millar et al. 2007). Rather than strive for restoration of a fixed pre-settlement condition, managers may want to increase tree, stand, and landscape resiliency. Future forests will likely be impacted by an extended fire season (Westerling 2006), increased human presence, wildland/urban interface development (Duane 1996), and other stressors (Millar et al. 2007, van Mantgem and Stephenson 2007).

All reconstruction studies and old forest survey data sets (McKelvey and Johnson 1992) suggest frequently burned forests had very low densities (ex. Lieberg [1902] estimated growing stock was only 35% of potential), a greater percentage of pine, a clustered pattern with highly variable canopy cover and a high percentage of the growing stock in more fire-resistant, large diameter classes. This reconstruction information gives general guidance but should not be taken as a strict numerical target for density or diameter distribution in silvicultural prescriptions. What the information probably better represents is inference about the cumulative process effects of fire, insects and pathogens, wind, and stand dynamics on forest conditions. Although fully restoring these processes may not be feasible, restoration should strive to move forests towards a condition that more closely resembles the evolutionary environment of these ecosystems. Many studies have shown that frequent, low-intensity fire has been a key process shaping Sierran mixed-conifer (ex. Agee et al. 1978; Vankat and Major 1978; Kilgore and Taylor 1979; Parson and DeBenedetti 1979). This suggests that restoration should manage fuel loads to keep fire within its historic range of severity and extent to avoid wholesale changes in stand composition and structure.

Restoration focused on affecting process intensity has at least two important benefits that current diameter-limit treatments lack: increasing forest heterogeneity and adaptation to changing climate conditions. Current restoration often focuses on structural targets consistently applied throughout a treated area. This uniform application, however, is unlikely to produce the variable stand structures and compositions that low-intensity wildfires produced in the past (Miller and Urban 1999, Hessburg et al. 2005). However, management keyed to manipulating the process of fire (i.e., its ecological 'work') would increase forest heterogeneity by producing different fuel conditions across a landscape. Thinning prescriptions designed to affect fire behavior would vary depending on topographic conditions within a stand (ex. a concave moist seep) and a stand's landscape position (i.e., aspect, slope and slope position) (see section 5). A second benefit of process-based management is that in wildland fire-use and prescribed burn areas, forest structure and composition are allowed to re-establish to modern dynamic equilibrium by adapting to fire that occurs under current climate and ignition conditions (Stephenson 1999, Falk 2006). If managers continue to use diameter guidelines in an effort to replicate early 19th century stand structures, they may not be creating a forest adapted to a warming climate. Annual fluctuations in temperature and precipitation are expected to increase in California with global warming (Field et al. 1999). In wildland fire use and prescribed burn areas, a management focus on fuels and their effect on fire behavior enable forest structure and composition to reach a dynamic equilibrium to changing climate conditions.

4. Sensitive Wildlife

An ecosystem management strategy that conserves wildlife and minimizes habitat impacts must be concerned with both the broader animal community as well as the specific needs for a subset of species of concern. For over 15 years, Sierran forest management has been devoting significant effort to meeting the needs of old-forest associated species, particularly the California spotted owl (*Strix occidentalis occidentalis)* (Verner et al. 1992) and the Pacific fisher (*Martes pennanti*). Sound wildlife management strategies need to account for species needs at a variety of spatial (microsite to foraging landscape) and temporal (immediate to long-term population viability) scales (Noss et al. 1997).

Managing for owl and fisher viability needs to account for a few shared characteristics of these top tropic species including territoriality, large home range size, strong associations with late seral forest elements, and long distance travel for foraging. Both species are strongly associated with Sierran forest stands characterized by large trees and dense canopy closure (Verner et al. 1992, Zielinski et al. 2004a). These features are consistently selected by spotted owls for nesting (North et al. 2000) and by fishers for denning and resting sites in the Sierra Nevada (Zielinski et al. 2004a, Zielinski et al. 2004b, Mazzoni 2002) and elsewhere. Fishers use cavities in living and dead conifers and hardwoods as daily refuges, and tend to select the largest individual trees in dense canopy stands. Individual trees are rarely reused as rest structures, at least consistently from night to night (Zielinski 2004a), so many different large trees are required. This behavior makes provision of resting habitat critical to fisher conservation. Spotted owls also use many different large trees within their home range for roosting (Verner et al. 1992). Large and/or decadent trees are less common in the Sierra Nevada than they once were and providing for this structure requires protecting existing large trees and managing for their future development.

Foraging habitat, unlike resting habitat, should be much easier to provide for spotted owls and fishers. The fisher's diet is very diverse and includes a variety of small mammals, birds, reptiles, fruits, and insects (Zielinski et al. 1999). Owls have a somewhat more specialized diet. In most locations they tend to take woodrats, flying squirrels, and deer mice, at least during nesting season (Williams et al. 1992, Forsman et al. 2004). Although our current knowledge of fisher and owl foraging habitats is fairly limited, we do know that their array of prey species are associated with a variety of forest conditions suggesting that habitat heterogeneity at different spatial scales across the landscape may be desirable for sustaining adequate food supplies (Carey 2003, Coppeto et al. 2006, Innes et al. 2007b). A cautious strategy would be emulating patterns created by natural disturbance to provide a heterogeneous mix of forest habitat across a managed landscape (Lindenmayer and Franklin 2002, Rempel 2007, North and Keeton in press). Given that fisher foraging habitat does not appear as limiting as their resting/denning habitat, and the latter requires much more forethought and time to develop, conservation and development of resting and denning habitat (i.e., large trees in stands with dense canopy cover) should be the primary concern.

4a. Management of large structures

Much of the public concern over forest management practices stems from possible impacts to old-forest associated species such as the fisher, California spotted owl, and northern goshawk (*Accipiter gentilis*). All three of these sensitive species depend on a forest structure that is usually dominated by large trees, snags, and downed logs which provide suitable substrate for nesting, denning, and resting sites. In some stands that have been depleted of larger trees, the best available structures may be intermediate-sized trees, generally defined as the 20-30" size class for conifers. In these stands, retaining conifers of this size is important not only for immediate wildlife needs, but also because they will become the next generation of large trees, (and eventually) snags, and logs. Fisher rest structures include live trees (e.g. cavities, broken tops); snags (e.g. cavities, broken tops, stumps); platforms (nests, mistletoe growths, witch's brooms); logs, and ground cavities (Zielinski et al. 2004a). We do not yet have a good understanding of how best to distribute potential rest sites or how many are needed. In the interim, we propose a cautious approach to identifying and managing potential resting structures (described in Section 5a).

4b. Other key structures and habitats

Other forest features that may be important to sensitive species as well as the broader wildlife community include hardwoods, shrubs, 'defect' trees, and riparian corridors. Hardwoods, particularly black oak (*Quercus kellogii*), are increasingly regarded as an important species for providing food and cavities. Acorns are used by many small and large mammals and birds as a food source (McShea 2000) particularly in large masting years (Tevis 1952, Airola and Barrett 1985, Morrison et al. 1987). Oaks also often have broken tops and large cavities from branch breakage, and are frequently used for resting and nesting sites by small mammals (Innes et al. 2007), forest carnivores (Zielinski et al. 2004a) and raptors (North et al. 2000, Richter 2005). In many areas, hardwoods are in decline because they have become overtopped and shaded by conifers. The larger oaks likely germinated and had much of their early growth in more open forest than exists today (Zald et al. in review). Provisions are needed to create open areas within stands to facilitate hardwood recruitment. Thinning around large oaks that are currently shaded, however, is a more difficult decision. The possibility that thinning will prolong the life of the oak as a rest structure needs to be balanced against the possibility that reducing the canopy around the oak will decrease the habitat value of the overall rest structure. For example, for fisher most rest sites are characterized by dense groupings of trees with high canopy cover (Zielinski et al. 2004a). Managers might consider thinning around some, but not all oaks if several are present within a stand.

In fire-suppressed forests, shrubs are often shaded out (Nagel and Taylor 2005, North et al. 2005), reducing their size, abundance, and fruit/seed production in low-light forest understories. Anecdotal narratives (Lieberg 1902, Muir 1911) and a few early plot maps (Eric Knapp, pers. communication) suggest shrub cover in active-fire conditions might have been much higher than in current forests, mostly due to large shrub patches that occupied some of the gaps between tree clusters. Some birds (Robinson and Alexander 2002) and small mammals (Coppeto et al 2006, Innes et al. 2007b) may be associated with these habitat patches. We also know that species of *Ceanothus* are an important source of available nitrogen (Johnson et al. 2005, Erickson et al. 2005) that persists even after the shrubs have been removed by fire (Oakley et al. 2003). In forests where shrubs are currently rare, managers should consider protecting what shrubs remain and increasing understory light conditions for shrub establishment and patch expansion. Patch size and configuration of such habitat should vary (see discussion on habitat heterogeneity in section 5).

Until recently, forest management practices typically removed decadent, broken-topped, or malformed trees that are actually some of the most important features of habitat for many wildlife species (Thomas et al. 1976, North et al. 2000, Zielinski et al. 2004a, Mazurek and Zielinski 2004). These ‘defect’ trees are some of the rarest structures in current forest conditions, often rarer than large trees. Any management strategy employed should consider means for preserving what remains and adding more of these features across the landscape.

Connecting habitat within a landscape using corridors has been extensively studied, but results often indicate suitable forest conditions within the corridor and the optimal distribution of corridors, varies by species (Hess and Fischer 2001). Habitat connectivity is expressed at different spatial scales for different species but is more important for mammals than birds (which move more easily between patches of suitable habitat) and for species, like the fisher, that move long distances on a regular basis. Currently we know little about fisher movement patterns or preferred foraging conditions although research addressing these issues is currently underway. Some observations (Purcell pers comm., Seglund 1995, Zielinski et al. 2004a) suggest riparian areas may be used disproportionately. Due to greater soil development and moisture retention, these corridors usually provide more vegetative cover and have greater plant and fungal abundance and diversity. Many small mammals are found in greater abundance in riparian areas, (Kattelmann and Embury 1996, Graber 1996, Meyer et al. 2007b) and some of these species are selected prey of old-forest associated species such as fishers. Riparian forests, however, are less moisture limited than upland areas, are highly productive, and now have some of the heaviest ladder and surface fuel loads of any Sierran forest communities (Bisson et al. 2003, Stephens et al. 2004). Recent western U.S. research suggests that although reduced, fire is still a significant influence on riparian forest structure, composition, and function in forests with historically frequent, low-intensity fire regimes (Olson 2000, Dwire and Kauffman 2003, Everett et al. 2003, Pettit and Naiman 2007). Though fire in Sierran riparian areas was probably less frequent than surrounding uplands, we do not yet know what its historic frequency, intensity and extent was in stream corridors. When inevitable wildfires burn these corridors they are likely to be high severity crown fires which can denude riparian areas of vegetation (Benda et al. 2003). Any management activity in riparian areas, including no action, has risks. Removal of any overstory or co-dominant trees may affect microclimate and plant diversity, adversely impacting habitat. We suggest riparian corridors be treated with prescribed fire in spring or late fall (after rains) to help reduce surface fuels. In moist conditions, some research (Beche et al. 2005) and observation (Dave McCandliss, Sierra N.F.) suggests low-intensity prescribed fire can reduce fuels while maintaining high canopy cover and large logs, if fuels have high moisture content. Overstory and understory vegetation, because of its habitat and fuel importance, should be used to define riparian corridor width rather than set distances such as 150 and 300 ft for annual and perennial streams.

Improving habit connectivity in forested landscapes for a wide array of wildlife is difficult because of the varying needs of different species. A cautious approach is to mimic landscape conditions that existed during an active-fire period. Studies in eastern Washington (Hessburg et al. 2005, 2007) and Baja's (Stephens et al. 2007b) mixed-conifer forests suggest these conditions were highly heterogeneous. Because these forests are similar to those in the Sierra Nevada, we believe a revised Ecosystem Management Strategy needs to include methods for increasing forest heterogeneity at multiple scales.

5) Importance of Heterogeneity

Creating vertical and horizontal heterogeneity in forests with frequent fire has been a challenge. Multi-layered canopies, often associated with Pacific Northwest old-growth forests (Spies and Franklin1988) , may not be the best model for mixed conifer because when adjacent trees are multi-layered, the continuity of vertical fuels can 'ladder' surface fire into the overstory canopy. There are conditions (e.g. mesic areas in drainage bottoms) that are conducive to vertical heterogeneity, but in general Sierra mixed-conifer forests do not support much of this condition. Horizontal heterogeneity, however, should be relatively common in Sierran mixed conifer. All of the Sierran reconstruction studies (Minnich et al. 1995, Barbour et al. 2002, Taylor 2004, North et al. 2007) suggest mixed conifer, under an active fire regime, had a naturally clumped distribution containing a variety of size and age classes.

5a.Within stand variability

At the stand level, vertical heterogeneity can still be provided by separating groups of trees by their canopy strata. For example, a group of intermediate size trees that could serve as ladder fuels might be thinned or removed if they are growing under large overstory trees. The same size trees in a discrete group, however, might be lightly thinned to accelerate growth or left alone if the group does not present a ladder fuel hazard for large, overstory trees. These decisions would be made using the revised silvicultural markings proposed in section 6f, where growing space is allocated by leaf area index among trees in different height strata. This strategy will produce within stand vertical heterogeneity, albeit in discrete tree clusters which will contribute to horizontal heterogeneity. There are conditions where multi-layered canopies can and should persist within a stand, notably within moist riparian zones with deep soils (see section 5b below).

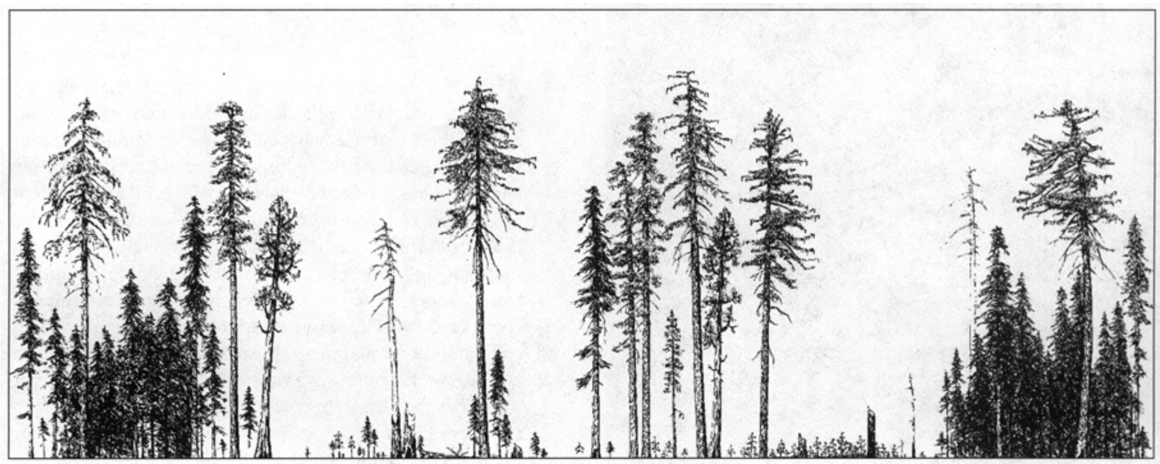


Figure 1: Transect of a mixed-conifer forest in Yosemite National Park's Aspen Valley which has experienced three understory burns within the last 50 years. Note that the stand has vertical heterogeneity but that trees in different canopy strata tend to be spatially separated (drawing courtesy of Robert van Pelt).

To increase horizontal heterogeneity we suggest using microtopography as a template. Wetter areas, such as seeps, concave pockets, and cold air drainages, may have burned less frequently or at lower intensity. Thinning, even of smaller trees, should be limited in these areas because with their potentially higher productivity and cooler microclimate, they may have historically supported greater stem densities, higher canopy cover and reduced fire effects. A concern with current management practices focused on reducing ladder fuels is that these microsite habitats would be eliminated. Some sensitive species, such as the fisher and spotted owl, may prefer these stand conditions for resting and nesting. Historical records indicate these species were present when Sierran forests had an active fire regime, suggesting pre-settlement forests may have contained higher density patches that either burned less frequently and/or at lower severity. In the absence of any information about the size or distribution of these high-density patches, our working hypothesis would be to identify moist, cool microsites on the landscape as locations that can sustain higher densities of tree and greater canopy cover. In contrast, upslope areas, where soils may be shallower and drier, and where fire can burn with greater intensity, historically probably had lower stem densities and canopy cover (Agee and Skinner 2005). These would be sites that might typically be found on south- and west-facing slopes where thinning might reduce the density of small or, where appropriate, intermediate trees, and ladder and surface fuels toward a more open condition. In some circumstances this thinning may reduce water stress, accelerating the development of large size in the residual trees. Within a stand, horizontal heterogeneity would be created by varying stem density according to potential fire intensity affects on stand structure.

5b. Landscape-level forest heterogeneity

There are few studies of landscape heterogeneity in the Sierra Nevada (Urban et al. 2000), so we've used research in other mixed-conifer forests to infer dynamics affecting large-scale forests conditions. In Baja's active-fire, Jeffrey pine/mixed conifer, Stephens et al. (2007b) found that 'average' stand characteristics such as snag density, large woody debris, tree density, basal area, and surface fuel loads were rare and occurred in approximately 15-20% of the sampled stands. Less than the 'average' conditions normally occurred in half of the area, while approximately one-third of the sample area actually contained higher levels of these structural elements and they were all in clumps. Across the landscape, all of these structural attributes varied by an order of magnitude in the localized (0.25 ac) plots.

In the Klamath Mountains, Taylor and Skinner (2004) found that mixed-conifer structure and composition varied by fire patterns which were controlled by landscape physiographic features. Fire intensity, and consequently a more open forest condition, increased with higher slope positions and more southwesterly aspects. In eastern Washington mixed conifer, Hessburg et al. (2005, 2007) also found a heterogeneous historic forest landscape shaped by topographic influences on fire behavior. We suggest creating this landscape heterogeneity in the Sierra Nevada by mimicking the forest conditions that would be created by the fire behavior and return interval associated with different slope positions and aspects. Stem density and canopy cover should be highest in drainages and riparian areas and than decrease over the mid slope and become lowest near and on ridge tops.

6. Revising Silvicultural Prescriptions

By necessity, recent Sierran silviculture has first been focused on reducing fire severity through fuels reduction. For many reasons including maintaining or restoring resilient forests, public safety and property loss, fuels reduction needs to remain a priority. We believe, however, that with some modification, wildlife and ecological objectives can also be meet.

6a. Importance of tree species

Diameter-limit prescriptions applied equally to all species do not account for the significant deficit of hardwoods and pines in current forests. Prescriptions that vary by species can retain hardwoods, which are important for wildlife, and favor pines which can increase the forest's fire resilience. Given their current scarcity, there are few instances which would warrant cutting either hardwoods or pines in mixed-conifer forests.

6b. Retention of 'defect' trees

Decadence or poor growth form does not justify removing an intermediate or larger tree. Sometimes prescriptions include thinning trees with multiple tops, rot, cavities, etc. in an effort to improve the genetic stock of the stand. Poor growth, however, may often result from injury (ex. lightning, wind breakage, struck by adjacent falling tree) in which case there is no genetic reason for removal, or from disease. Disease incidence does not necessarily indicate an individual is genetically more susceptible and therefore should be 'culled'. Many trees become diseased simply by proximity to other diseased individuals or stochastic events (ex. bird transport of mistletoe). More importantly, cavities, multiple tops, and mistletoe brooms are important structural features for many wildlife species. Modern Sierran forests have a significant shortage of these 'decadent' but essential habitat structures.

6c. Revising the desired diameter distribution

The proposed silvicultural approach is a multiaged stand strategy driven by the need for wildlife habitat (including old-forest associate species such as fisher), fire-resistant stand structures, and restoration of stand and landscape patterns similar to active-fire conditions in mixed-conifer forests. Although we use the term multiage, we are most interested in size and structure, and their associated ecological attributes. Multiaged stands are advocated as a flexible means of including variable stand structures with two or more age classes, and integrating existing stand structure features into silvicultural prescriptions. More traditional forms of uneven-aged silviculture were heavily reliant on achieving a reverse-J diameter distribution that reduced large tree retention (O'Hara 1998). This is perhaps especially true in the Sierra's mixed-conifer forests where fire was a major force in shaping size class distributions (North et al. 2005b, 2007). The reverse-J diameter distribution prescribes a structure with a surplus of small trees and limited space for large trees. This stand structure is inconsistent with recent research findings and current land management priorities in western forests. Reconstruction research suggests that fire significantly influenced diameter distributions, notably reducing small tree abundance while retaining fire-resistant, large diameter trees.

6d. Groups of large trees

Clusters of intermediate to large trees (i.e., 20-30" DBH [diameter at breast height]) are sometimes marked for thinning in the belief that they are overstocked and thinning would reduce moisture stress. Some evidence, however, suggests these groups of large trees may not be moisture stressed by within group competition because they have deep roots which can access more reliable water sources including fissures in granitic bedrock (Akerley 1981, Hubbert et al. 2001, Hurteau et al. 2007). Reconstructions of Sierran forests with active fire regimes (Bonnickson and Stone 1982, Minnich et al. 1995, Barbour et al. 2002, Taylor 2004, North et al. 2007) have consistently found large trees in groups. These groups, however, can be at risk if intermediate and small trees grow within the large tree groups. These small and intermediate trees should be thinned to reduce fire laddering and collateral mortality from beetles attracted to the moisture-stressed smaller trees (Smith et al. 2005).

6e. Managing the intermediate (i.e. 20-30") size class

There's solid scientific evidence documenting the importance of large tree structures in forests for many ecological processes and their value for wildlife habitat (see summaries in Kohm and Franklin 1997, Lindenmayer and Franklin 2002). 'Large', however, varies with forest type and site productivity, and there's no one size at which a tree takes on these attributes. We only address this question of 20-30" trees because it is so pivotal in the current management strategies for Sierran forests, and is driving much of the discussion around fuel treatment thinnings.

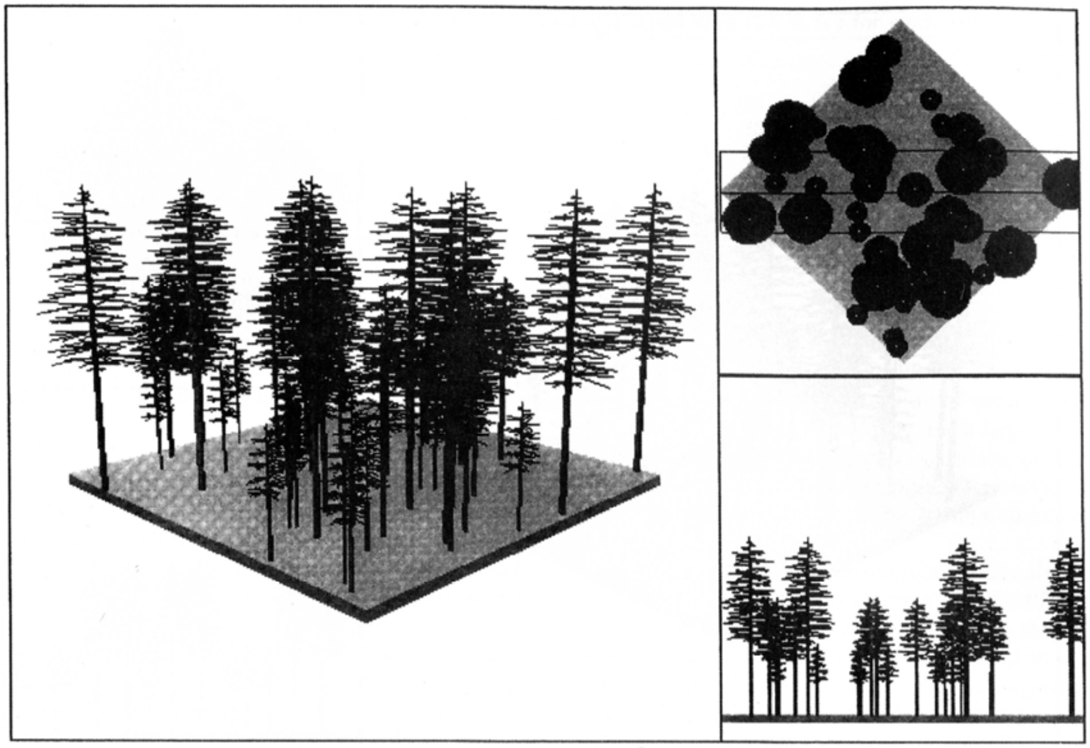
So, what is achieved by thinning intermediate sized (20-30") trees? Some research suggests that for managing fuels, most of the reduction in fire severity is achieved by reducing surface fuels and thinning smaller ladder-fuel trees (see summaries in Agee et al 2000 and Agee and Skinner 2005). What is considered a ladder fuel varies from stand to stand but typically these are trees in the 10" to 15" DBH classes. If trees larger than this are thinned, reasons other than fuels treatment should be provided. These may include additional fuels reduction such as thinning crown bulk density in strategic locations. Or it could be other ecological objectives such as restoration of an active fire stand structure, accelerating the development of large size in the leave trees, or managing for open habitat that includes shrubs. There may be socio-economic purposes for harvesting intermediate sized trees such as generating revenue to help pay for fuels treatment or providing merchantable wood for local sawmills. Clear statement of the objectives for thinning intermediate-sized trees will help clarify management intentions.

Under what conditions, could larger trees be thinned? We suggest the following criteria but stress that most of this is working hypotheses built from lines of evidence. We believe these criteria should be revised as better science develops. The first selection criteria should be species: thinned intermediate-size trees should only be shade-tolerants such as white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*) and incense-cedar (*Calocedrus decurrens*). In mixed conifer, intermediate-size pines and hardwoods should rarely if ever be thinned because of their relative scarcity and importance to wildlife and fire resilience. A second criterion would be tree growth form: some intermediate-size trees can still function as a ladder fuel, particularly those that were initially grown in more open conditions. These trees can have live and dead limbs that extend down close to the forest floor providing a continuous fuel ladder. A third condition is middle to upper slope topographic position. In these slope positions some thinning of intermediate-size trees may help accelerate the development of large size in the leave trees by reducing competition for soil moisture and sunlight. In contrast to these upland forest conditions, we would not apply these criteria to riparian areas, moist microsites often associated with deeper soils, concave topography, or drainage bottoms because these areas may have supported higher tree densities and probably greater numbers of intermediate-sized trees (Meyer et al. 2007a).

6f. Allocation of growing space by leaf area index

We propose a form of multiaged silviculture for southern Sierra mixed conifer that is flexible to meet diverse forest objectives, accommodate retention of existing and recruitment of future large structures, and that provides for sustainability. The silvicultural system is based on a scientific foundation where leaf area represents the occupied growing space of trees and stands. By segmenting stand-level leaf area index among canopy strata, tools can be developed to allocate growing space and provide flexibility for creating heterogeneous stand structures and meeting diverse ecological objectives (Figure 2; O'Hara 1996, O'Hara and Valappil 1999). For example, leaf area could be allocated primarily to larger trees in one stand where these large trees are present and important structural components. In other stands, large trees may be absent and leaf area would be allocated to developing cohorts to expedite development of large structural features. Trees would be harvested and timber would be an output, but the silvicultural system's focus is on designing retained stand structures, not what is removed for harvest. On the ground, this system would provide for a diverse stand structure with both vertical and horizontal heterogeneity. It would be prescribed one stand at a time and would create landscape-level heterogeneity through varying the stocking regime. Treatments are intended to create a mixture of structure that would be sustained throughout the period between active management.

The proposed silvicultural system would be simple to apply in the field. It recognizes canopy strata as the primary unit for allocation of growing space. Within these groups, space would be allocated to species or species groups. A resulting stocking matrix might consist of three canopy strata and three species groups (ex. pines, white fir and incense-cedar, and others) providing for a stocking matrix with nine cells. This approach will generally simplify the marking of trees and also accounts for modifications of species composition (O'Hara et al. 2003). This silvicultural revision will require a research project to adapt the MultiAge Stocking Assessment Model (MASAM) model to Sierra Nevada mixed conifer.



Ponderosa pine MASAM - OREGON					
	USER-SPECIFIED VARIABLES				
TOTAL Leaf Area Index (LAI)	6				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Number of Trees/Cohort/Acre	25	40	55	0	120
Percent of LAI/Cohort	50	35	15	0	100
	DIAGNOSTIC INFORMATION				
	Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL
Leaf Area Index/Cohort ECC	3.0	2.1	0.9	0.0	6.0
Leaf Area Index/Cohort BCC	1.3	0.7	0.0		2.0
Leaf Area/Tree (ft^2) ECC	5227.2	2286.9	712.8	0.0	
BA/Cohort (ft^2/ac) ECC	72.5	47.6	19.8	0.0	139.8
BA/Cohort (ft^2/ac) BCC	29.7	14.4	0.0		44.1
Avg. Vol. Increment/Tree (ft^3/yr) ECC	1.02	0.64	0.18	0.00	
Avg. Vol. Increment/CC (ft^3/ac/yr)	20.7	16.3	5.0	0.0	42.0
Quadratic Mean DBH/Cohort (in) ECC	23.1	14.8	8.1	0.0	
Tree Vigor (in^3/ft^2/yr)	0.408	0.460	0.440	0.000	
Stand Density Index ECC	95.2	74.6	39.4	0.0	209.2
Stand Density Index BCC	46.6	28.7	0.0		75.3

Figure 2. An example of a three-strata (or three-cohort) Oregon ponderosa pine stand using the MASAM approach for growing space allocation. Growing space can be allocated in a variety of patterns providing flexibility in stand structure design (from O'Hara et al. 2003).

7. Research Needs

1. Quantify the leaf area/growth relationships needed to develop stocking control relationships for Sierra Nevada mixed conifer. This will allow completion of a Sierra Nevada MASAM for the Kings River Project (KRP) area or any other area in the southern Sierra where this approach could be implemented. This tool will allow the design and assessment of a variety of multiaged stand structures that include, among others, older residual trees, development of pre-settlement structures, and accommodation of prescribed burning regimes.

2. Development and implementation of an adaptive monitoring strategy to assess the efficacy of a Multiaged Strategy at both the stand and landscape scales. This information will include both on-the-ground monitoring of treated stands and simulations using SN-MASAM. This input will be used to refine this strategy over time and make large-scale assessments of landscape patterns for wildlife habitat, potential fire behavior, and general diversity of vegetation patterns. A Multiaged Strategy would be adjusted pending results of monitoring efforts to accommodate other resource objectives such as wildlife, fire, or other necessary changes.

3. Assess the potential outcomes of this proposed silvicultural approach on vegetation response and wildlife habitat features of interest. This could be combined with a comparison to other possible silvicultural strategies to provide a basis from which to evaluate the similarities and difference of different approaches. Research would also assess the effects of any treatment on predicted fisher resting habitat using either a predictive microhabitat model (Zielinski et al. 2004a) or an FIA-protocol based habitat model (Zielinski et al. 2006). The former has already been used to evaluate the effect of Fire and Fire Surrogate treatments on predicted fisher resting habitat (Truex and Zielinski in review), and the projected effects of Kings River treatments on fisher resting habitat (R.Rojas, unpubl).

4. Determining how forest structure and composition varied by topographic feature under an active-fire regime in the Sierra Nevada. Currently there have been studies in the Klamath Mountains and eastern Washington, but no information is available for California forests.

The research would identify which topographic features matter, and stand structure and fuels loads associated with different physiographic areas.

5. Fire history studies of riparian areas are needed to determine fire frequency, intensity, and extent. How far does the riparian influence for dampening fire extend away from the stream? What were historic fuel loads in these forests? How can riparian systems be managed to reduce adverse fire effects while maintaining wildlife habitat? In current wildfires, are riparian forests typically experiencing high-intensity crown fires or are moister fuels and microclimate still damping fire behavior?

6. A closer examination of the tree size distribution within female fisher home ranges is needed to establish the means and variances of tree number/density by size class, for both conifers and hardwoods. This would require overlaying the boundaries of female fisher home ranges, which have been estimated on the Sierra and Sequoia National Forests (Mazzoni 2002, Zielinski et al. 2004b), and then using plot-based or transect-based sampling methods to collect the tree data within these areas. Once we have estimates of the average number of, say, white fir between 20 – 30" DBH per acre within the average female home range, we will be able to compare this with the average number of this species and size class predicted to occur as *residuals* after proposed treatments. If the number/acre of trees within a specific target species/size class category expected after harvest is significantly *lower* than what occurs in home ranges that females have selected, then the proposed management activity would not be consistent with fisher conservation.

8. Summary Findings

Fundamentally we believe that an ecosystem management strategy using a multiage silvicultural system is appropriate for managing southern Sierra National Forests. Important facets of this strategy are:

- *THE ECOLOGICAL IMPORTANCE OF FIRE: Prescribed fire can help reduce surface fuels and restore some of the ecological processes that mixed-conifer forests have evolved with.*

- *FUELS MANAGEMENT: When stands cannot be burned, reducing fuels to moderate fire behavior is still a key priority because wildfire is likely to burn the area eventually. A few of the ecological benefits of fire are achieved with mechanical fuel reduction, but thinning is not an effective substitute for fire in affecting ecosystem processes. Reduction of surface fuels should be an equal priority with reducing ladder fuels.*

- *LIMITED USE OF CROWN SEPARATION FUELS TREATMENTS: Reducing crown bulk density and increasing tree crown separation should be sparingly applied only to key strategic zones. More research is needed, but current models suggest its effects on reducing crown fire spread are limited, and the regular leave-tree spacing does not mimic tree patterns in active-fire regime forests.*

- *TREATMENTS FOCUSED ON AFFECTING FIRE BEHAVIOR: Efforts to restore pre-European forest conditions are likely to fail in the face of climate change and also do not provide flexible prescriptions that adapt to different site conditions. Treatments should focus on affecting fire behavior by manipulating fuel conditions, allowing forests to equilibrate to fire under modern conditions and increasing forest heterogeneity.*

- *RIPARIAN FOREST FUELS REDUCTION: Prescribed burning of riparian forest is needed to help reduce fuels in these corridors which are also important wildlife habitat. For the initial prescribed fire, managers should consider burning in spring or late fall when fuel moisture levels are relatively high.*

- *SPATIAL VARIAION IN FOREST STRUCTURE: 'Average' stand conditions may be rare in active-fire forests because the interaction of fuels and stochastic fire behavior produces highly heterogeneous forest conditions. Creating 'average' stand characteristics replicated hundreds of times over a watershed will not produce a resilient forest. Managers should strive to produce different forest conditions and use topography as a guide for varying treatments. Within stands, important stand topographic features include concave sinks, cold air drainages, and moist microsites. Landscape topographic features include slope, aspect, and slope position.*

- *STAND-LEVEL TREATMENTS FOR SENSITIVE WILDLIFE: Areas of dense forest and high canopy cover will be needed for California spotted owls and Pacific fishers. We suggest identifying those areas as places where historically fire would have burned less frequently or at lower severity, due to cooler microclimate and moister soil and fuel conditions.*

- *LANDSCAPE-LEVEL TREATMENTS FOR SENSITIVE WILDLIFE: In the absence of better information owl and fisher preybase habitat may best be meet by mimicking the variable forest conditions that would be produced by frequent fire. Reductions in stem density and canopy cover would emulate how a site's slope, aspect, and slope position might have affected fire behavior and the stand structure that would have resulted from that fire behavior.*

- *SILVICULTURAL MODEL/STRATEGY: The frequency distribution of tree diameters in Sierran mixed-conifer forest subject to frequent low-intensity fire was highly variable but generally flat due to periodic episodes of fire-induced mortality and subsequent recruitment. Stand treatments should strive to significantly reduce the proportion of small trees and increase the proportion of large trees as compared to current stand conditions.*

- *FIELD IMPLEMENTATION OF SILVICULTURAL STRATEGY: Marking rules should be based on crown strata or age cohorts (a proxy for size/structure cohorts) and species rather than uniform diameter limits applied to all species.*

- *TREE SPECIES SPECIFIC PRESCRIPTIONS: Hardwoods and pines, with much lower densities in current forests compared with historical distributions, would rarely be thinned. The emphasis of thinning would be focused on firs and incense cedar. Pine plantations need to be addressed separately.*

- *ALLOCATION OF GROWING SPACE: A large proportion of the growing space would be allocated to the largest tree stratum.*

- *SPATIAL DISPERSION OF TREATMENTS: Trees within a stratum (i.e. canopy layers or age cohorts) would often be clumped, but different strata, for fuels reasons, would often be spatially separated. Particular attention should be given to providing horizontal heterogeneity to promote diverse habitat conditions.*

- *TOPOGRAPHIC FEATURES CREATE DIFFERING CIRCUMSTANCES FOR STAND DENSITY AND THUS HABITAT CONDITIONS: Basic topographic features; i.e. slope, aspect, and slope position result in fundamental differences in vegetation composition and density producing variable forest conditions across the Sierra's landscape. Drainage bottoms and north/east facing slopes should generally have greater site capacity and thus retain greater tree densities and basal areas.*

- *ASSESSMENT OF TREATMENT EFFECTS: Emphasis is on what is left in a treated stand, rather than what is removed.*

- *LARGE TREES AND SNAGS: Given their current deficit in mixed-conifer and the time necessary for their renewal, most large trees and logs should be protected from harvest and inadvertent loss due to prescribed fire.*

- *RETENTION OF SUITABLE STRUCTURES FOR WILDLIFE NEST, DEN, AND REST SITES: Trees providing suitable structure for wildlife include large trees, and trees with broken tops, cavities, platforms, and other malformations that create structure for nests, dens, etc. These structures typically occur in the oldest trees. A process for identifying and thus protecting such trees by field staff should be developed and adopted for all future inventories and prescription marking* *crews. The Green Diamond Resource Company has developed a guide that could serve as a useful model.*

- *RETENTION OF DOWNED LOGS AND SNAGS: Restoration of fire, especially prescribed fire, should consider effects to large downed logs and snags. These important features should be retained wherever possible. However, the distribution of such features is spatially quite variable and need not be implemented uniformly across the landscape. Attention should also be devoted to restoring the log creating process; creation of logs and the retention of logs on the ground operate at different time scales.*
- *TREATMENT OF INTERMEDIATE SIZED TREES: In most cases thinning20-30" dbh trees will not affect fire severity and therefore other objectives for their removal should be clearly identified. Where those objectives are identified, silvicultural prescriptions would only remove intermediate-sized trees when they are shade-tolerants on mid or upper slope sites.*

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