
Forest Restoration and Fire: Principles in the Context of Place

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Abstract: *There is broad consensus that active management through thinning and fire is urgently needed in many forests of the western United States. This consensus stems from physically based models of fire behavior and substantial empirical evidence. But the types of thinning and fire and where they are applied are the subjects of much debate. We propose that low thinning is the most appropriate type of thinning practice. Treating surface fuels, reducing ladder fuels, and opening overstory canopies generally produce fire-safe forest conditions, but large, fire-resistant trees are also important components of fire-safe forests. The context of place is critical in assigning priority for the limited resources that will be available for restoration treatments. Historical low-severity fire regimes, because of their current high hazards and dominance by fire-resistant species, are the highest priority for treatment. Mixed-severity fire regimes are of intermediate priority, and high-severity fire regimes are of lowest priority. Classification systems based on potential vegetation will help identify these fire regimes at a local scale.*

Restauración de Bosques y Fuego—Principios en el Contexto del Sitio

Resumen: *Existe un amplio consenso de que en muchos bosques del oeste de EE.UU. se requiere con urgencia un manejo activo mediante tala y fuego. Este consenso se basa en modelos físicos de comportamiento de fuego, así como en importante evidencia empírica que aumenta cada año. Pero los tipos de tala y fuego y el lugar en que se aplican, son temas de mucho debate. Proponemos que la tala reducida es la más apropiada. El tratamiento de combustibles de superficie, la reducción de combustibles escalera y la apertura de doseles generalmente producen condiciones a salvo de fuego en los bosques, pero árboles grandes resistentes al fuego también son componentes importantes de bosques a salvo de fuego. El contexto del lugar es crítico en la asignación de prioridades a los limitados recursos disponibles para tratamientos de restauración. Los regímenes de fuego de baja intensidad, debido a sus altos riesgos actuales y la dominancia de especies resistentes al fuego, son la mayor prioridad para el tratamiento. Los regímenes de fuego de severidad mixta son de prioridad intermedia y los regímenes de fuego de alta severidad son de menor prioridad. Los sistemas de clasificación basados en la vegetación potencial ayudarán a identificar estos regímenes de fuego a escala local.*

Introduction

Transformation of the forested landscape in the western United States, especially dry, low-elevation forests dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), began in the second half of the nineteenth century with the introduction of livestock grazing. Beginning in the late nineteenth century and accelerating after World War II, selective logging of old, fire-resistant trees, extensive road building to facilitate logging, fire exclusion, and

livestock grazing continued trends of forest and watershed degradation. Approaches to addressing these daunting problems are being developed and implemented, but a strategic approach will be required because restoration resources are limited. Strategically focused, integrated approaches are needed that will provide maximum benefits for a given cost while minimizing unintended adverse effects (Agee 1996; Rieman et al. 2000; Finney 2001). We summarize here the restoration potential of active management and principles related to fire resiliency that

should be applied when considering active management, and we emphasize a context of place in the planning process.

Restoration Concepts

There is broad agreement that restoration in some form and to some degree—of fire regimes, habitats, populations of fish and wildlife, productivity of soils, watershed integrity, and disturbance patterns—is appropriate (ICBEMP 2000; U.S. Department of Agriculture Forest Service 2000; Weatherspoon & Skinner 2002). However, there is more disagreement concerning restoration objectives and implementation strategies. Restoring landscapes to some semblance of pre-1850 conditions, or their “historic range of variability,” is one common suggestion. Advocates presume that forest stands and landscapes restored to past conditions are more likely to support healthy populations of wildlife and fish. Habitats would be more like those to which species had adapted over thousands of years, and disturbance processes (fire, insects, disease, flooding, landsliding) could operate more sustainably in a more resilient landscape. However, although knowledge of historical conditions will be useful in guiding restoration efforts, attempts to precisely recreate past conditions will not be desirable or feasible (Christensen 1988; Swanson et al. 1994; Gregory 1997; Hessburg et al. 1999; Landres et al. 1999; Millar & Woolfenden 1999; Moore et al. 1999; Tiedemann et al. 2000; Allen et al. 2002).

Knowledge of historic conditions can help clarify the types, extent, and causes of ecosystem changes and can help identify management objectives and restoration priorities (Hessburg et al. 1999). Climates are now different than at any historic time, however, and will be different in the future (Millar & Woolfenden 1999). Species have been irrevocably added and subtracted, and the undesirable portion of the modern human imprint cannot be entirely eliminated. Historical reconstructions can provide good estimates of the large-tree component of past forests, but they are less reliable for small trees or other ecosystem elements such as herbaceous vegetation or wildlife (Fulé et al. 1997; Harrod et al. 1999). Although past fire regimes may be more accurately estimated than forest structure and composition (Stephenson 1999), “the natural fire regimes of the past are not the regimes of the present, nor will they be the regimes of the future” (Agee 1998). Conditions other than historic (or “natural”) may need to be maintained to provide essential habitat for at-risk wildlife (ICBEMP 2000; Wisdom et al. 2000). Conditions that are “unnatural” yet sustainable and desirable may be quite appropriate for many state, private, and Native American lands.

Potential conflicts or trade-offs among reasonable objectives need to be recognized in setting restoration goals.

Creating stands that are highly resistant to severe fire may unintentionally disturb soil, reduce canopy cover, and affect some fish and wildlife species (Rieman & Clayton 1997; Gresswell 1999). There are also fire-behavior trade-offs. Thinning of codominant trees will contribute to restoration of more open stand conditions in some areas and increase the growth of forbs and shrubs, which retain moisture until later in the season, reducing fire behavior (Agee et al. 2002). Yet opening the canopy can increase fire behavior by lowering the moisture content of dead surface fuels and increasing surface windspeed (van Wagendonk 1996; Weatherspoon 1996; Agee et al. 2000).

Roads have many adverse ecological effects (Furniss et al. 1991; Noss & Cooperrider 1994; Rieman & Clayton 1997; Jones et al. 2000; Trombulak & Frissell 2000) but are paradoxical in terms of fire management. They open access so that human-caused ignitions increase but also decrease response time to wildfires, act as holding lines, and make prescribed fire easier to apply (Agee 2002). Most restoration effort can be focused on the substantially roaded portion of the landscape. In unroaded areas needing active management, prescribed fire with minimal necessary thinning and no road construction may be appropriate to maintain these important areas as reservoirs of biological diversity and ecological baselines (Noss 1999). The spatial focus of active management to alleviate road impacts and that to improve forest integrity will overlap considerably (Lee et al. 1997; Rieman et al. 2000).

Restoration Treatments

Ecological restoration efforts are often categorized as either active or passive. This can be a useful distinction, but the term *passive restoration* suffers from potential confusion with *passive management*, which some people consider equivalent (at least in some circumstances) to mere neglect or inattention to the needs of the land (Agee 2002). Passive restoration is the “cessation of . . . activities that are causing degradation or preventing recovery” (Kauffman et al. 1997) and can be considered the first step in restoration (National Research Council 1996).

The primary active restoration techniques we considered are thinning and prescribed fire. However, other active treatments focused on roads, weeds, livestock, and streams will also be needed. Thinning appropriate for restoration will focus on the cutting and removal of small trees and is variously known as understory thinning, thinning from below, or low thinning. Possible standards for placing boundaries on appropriate low thinning include diameter limits and percentile approaches. Diameter limits, such as restricting removal to trees <30 cm or <50 cm is one way to approach the problem, but the limit should vary by site. Trees that invaded some forests after fire

Table 1. Factors that increase fire resilience (adapted from Agee [2002] and Hessburg & Agee [2003]).

<i>Principle</i>	<i>Effect</i>	<i>Advantage</i>	<i>Concerns</i>
Reduce surface fuels	reduces potential flame length	control easier; less torching	surface disturbance less with fire than other techniques
Increase height to live crown	requires longer flame length to begin torching	less torching	opens understory; may allow surface wind to increase
Decrease crown density	makes tree-to-tree crown fire less probable	reduces potential for crown fire	surface wind may increase and surface fuels may be drier
Keep big trees of resistant species	less mortality for same fire intensity	generally restores historic structure	less economical; may keep trees at risk for insects

exclusion became effective can exceed 50–60 cm diameter, whereas on other sites trees that are 200 years old can be well below this size. Another approach is a percentile method, in which trees are ranked by size, and some size limit, such as the seventy-fifth percentile, is defined. This assures that the largest 25% of trees is left. Both approaches are likely to work best if applied in the context of place rather than being arbitrarily defined to fit all situations.

The majority of the trees removed in such thinnings are too small to have commercial value by conventional standards, but efforts are underway in the West to develop processing methods and markets for ever-smaller material. Before private investment emerges, assurances will be required that a supply of such material will be provided. Some trees thinned as a by-product of restoration activities will have commercial value (R. E. Noss. 2000. Society for Conservation Biology comment letter on U.S. Forest Service Roadless Areas Protection Initiative.). Restoration thinning may appropriately include the removal of dead trees, but traditional “salvage” logging will not provide restoration benefits. Removal of large, pre-1850 trees solely to pay for treatment will undermine the credibility of restoration efforts (Weatherspoon & Skinner 1995; Agee 1997b). Thinning is unlikely to meet all ecological objectives unless it is combined with prescribed fire (Weatherspoon 1996; National Research Council 1999; Lynch et al. 2000; Weatherspoon & Skinner 2002). Despite considerable anecdotal, modeling, and common-sense support for restoration thinning, scant empirical research has been done on the subject (van Wagtenonk 1996; Agee 1997a; Stephens 1998; Omi & Martinson 2002; Pollet & Omi 2002). Although additional scientific research is necessary, much can also be learned from routine monitoring, especially if it is structured to reflect a more consistent case-study approach (Shrader-Frechette & McCoy 1993).

Restoration objectives may be accomplished by prescribed fire alone in some forest types and conditions (Agee & Huff 1986; Biswell 1989; Weatherspoon 1996). It has been the primary restoration technique in drier forests of U.S. national parks. Yet prescribed fire applied too broadly could homogenize the landscape, create smoke problems, and damage wildlife habitat (Tiede-

mann et al. 2000). It can kill large trees that are intended to be saved by treatment (Agee 2003). The proportion of a landscape requiring treatment in order to have a significant effect on the spread and severity of wildfire is unknown. It is probable that areas less manipulated will be less effective per unit area, so that larger expanses of the landscape will have to be treated (Agee et al. 2000). Patterns of fuel treatment can affect fire intensity or rate of spread, and this topology has implications for designing landscape-level fuel-treatment patterns (Finney 2001).

Factors of Fire Resilience

A forest that is fire-resilient has characteristics that limit fire intensity and increase the resistance of the forest to mortality (Table 1). The first principle is to manage surface fuels to limit the flame length of a wildland fire that might enter the stand. This is generally done by removing fuel through prescribed fire, pile burning, or mechanical removal. This reduces the potential energy of a wildland fire and makes it more difficult for a fire to jump into the canopy (Scott & Reinhardt 2001). The second principle is to make it more difficult for canopy torching to occur by increasing the height to flammable crown fuels. This can be accomplished through pruning, prescribed fire that scorches the lower crown, or removal of small trees. The third principle is to decrease crown density by thinning overstory trees, making tree-to-tree crowning less probable. This will not be necessary on all sites and will be effective only if linked to the application of the first two principles (Perry et al. 2004 [this issue]). The fourth principle is to keep large trees of fire-resistant species (Hummel & Agee 2003). If fire behavior is successfully reduced but the fire is burning under fire-sensitive trees, high-severity fire will still occur as the trees may still all be killed. Active management can have positive or negative effects on fire-hazard potential (Table 2).

The influence of species composition and large trees on fire-resilient forests is illustrated by a simulation of fire effects (Fig. 1) based on the First Order Fire Effects Model (Reinhardt et al. 2002). A forest type with a historic low-severity fire regime—low-elevation

Table 2. Immediate effects of fuel treatment on factors that can affect fire behavior (Scott & Reinhardt 2001).*

Fuel treatment	Surface fuel load	Dead fuel moisture	Canopy base height	Bulk density	
				wind	canopy
Overstory thinning	I	D	I/NE	I	D
Understory removal	I		I		D/NE
Pruning	I		I		
Pile burning	D				
Whole-tree yarding	D				
Broadcast burning	D		I/NE		

*A blank indicates no effect; I, increase; D, decrease; NE, no effect.

ponderosa pine/Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco)—is contrasted with a historic high-severity fire regime—high-elevation subalpine fir (*Abies lasiocarpa* [Hook.] Nutt. and of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) at various flame lengths. The ponderosa pine stand with historic structure suffers little mortality until flame lengths exceed 1.8 m. A similar species composition of smaller trees, similar to many second-growth pine-fir stands across the western United States, suffers higher mortality, but loss of basal area remains below 25% until flame lengths are 1.8 m or greater. If fuel treatments can reduce flame lengths under worst-case fire weather to 1.2 m or less, these forests will survive

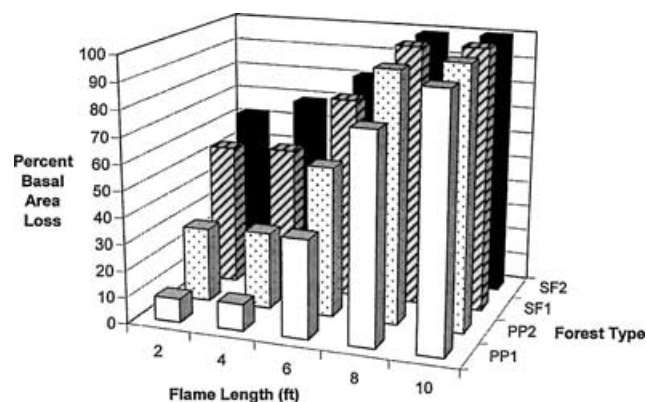


Figure 1. Percent loss of basal area by flame length for four classes of forest type or structure: PP1, historic mixed-conifer stand dominated by ponderosa pine with some Douglas-fir (density 15/ba, basal area 15 m²/ba, trees 40–50 cm in diameter); PP2, same species composition and basal areas as PP1 but higher density (50/ba) and therefore smaller trees (15–25 cm in diameter); SF1, stand of subalpine fir and lodgepole pine with the exact structure characteristics of PP2, except these two species are substituted for ponderosa pine and Douglas-fir; SF2, stand of denser subalpine fir and lodgepole pine with 30 m²/ba of basal area.

wildfire well. Restoration here will be ecologically effective at reducing wildfire damage.

The high-elevation forest types have fewer fire-resistant species (Peterson & Ryan 1986), so the subalpine fir-lodgepole pine stand with the same structure as the second-growth ponderosa pine stand incurs about twice the loss of basal area, even at low flame lengths. Flame lengths of 1.8 m or higher create high-severity basal area losses of 70% or more. A typical natural stand structure in subalpine fir and lodgepole pine, with higher density and more small subalpine fir, incurs even greater losses. Investments in fire resistance by fuel treatment will be less effective in these higher-elevation stands.

Scale is an important parameter to consider in restoring fire-resistant forests. If fuel treatments are small and scattered, they may not be effective in fragmenting landscape fuel loads, and their efficacy at the stand level can be overwhelmed. On the 1994 Tyee fire in Washington, small treated areas of mixed-conifer forest underburned while adjacent untreated areas burned with crown fires. The heat created by the crown fires passed over the treated areas and scorched the tops of the trees that were later underburned. Many of these trees later died from the sandwiched scorch effect (J. K. Agee, personal observation). Empirical evidence from wildfires also supports the concept that areas treated with the goal of reducing fire hazard will burn with less severity than adjacent untreated areas (Omi & Martinson 2002). In the 2002 Hayman fire in Colorado, many areas where fuels had been treated before the fire experienced lower-severity effects than adjacent untreated areas (Finney et al. 2002a). Fuel treatment was not always successful in lowering severity, particularly during periods of incredibly severe fire weather (winds to 135 kph and fuel moistures of below 6% in all size classes). Under less severe conditions, fuel treatments appeared to alter severity, except where the treatments were carried out on a very small local scale or where they had been applied more than 10–15 years previously.

A Context of Place

Place is the most significant and most misunderstood element of the decision about where to carry out active restoration treatments. Some forest types are in critical need of active restoration, and others need no treatment at all. Recent national analyses suggest that the scale of needed restoration is immense, on the order of over 70 million acres (25 million ha), mostly in the West. Almost all of this area, designated condition class 3, occurs in low-severity fire regimes (Schmidt et al. 2002), and because of the coarse scale of the analysis, is generally not accurate or usable at the subregional scale. We suggest that more local classification such as the plant association (Daubenmire 1968) or plant association group, which is

an aggregation of closely allied plant associations within a forest series, has more utility at the fine scale.

Low-Severity Fire Regimes

Dry pine and mixed-conifer forest comprise most of the western low-severity fire regimes. Forests were typically shaped by what is sometimes referred to as a “stand-maintenance” fire regime of low-intensity, frequent fires that generally burned grasses, brush, small trees, and fallen needles and branches but had little effect on older trees with thick insulating bark. The death of lower branches from shading or the effects of fire raised the bottom of the canopy to the point where it was not adversely affected by typical fires. In extremely hot and dry weather, fires would tend to cover a larger area but still were unlikely to kill overstory trees (Agee 1997b). Although ponderosa pine is the most wide-spread forest species exhibiting these characteristics, similar dynamics pertained in areas where other fire-resistant species—Douglas-fir, Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), western larch (*Larix occidentalis* Nutt.), and many species of oak (*Quercus* spp.)—grow either in association with ponderosa pine or as dominants.

Although some areas still resemble historic conditions, it is these dry pine and mixed-conifer forests that typically have been changed the most by human activities in the last 150 years. Heavy livestock grazing depleted the fine fuels that carried the light, frequent fires and exposed mineral soil seedbeds for abundant young ponderosa pine that often became established before 1900 (Belsky & Blumenthal 1997; Miller & Rose 1999; Swetnam et al. 1999). Fire suppression beginning after 1910 allowed far more of these trees to persist, and logging concentrated on large, old trees (Biswell et al. 1973). These forests may have been deprived of 10 or more natural fire cycles. The result is forests that, as the result of continuing fire suppression, tend to burn less frequently, but when they do burn the fire is much more likely to reach the forest canopy and spread as a crown fire, killing many or all of the overstory trees. A historically low-severity fire regime has turned into a high-severity or mixed-severity fire regime over millions of hectares in the West (Morgan et al. 1996; Hann et al. 1997). These higher-severity fires are more apt to have detrimental effects on soils, watersheds, and wildlife habitat. And they can have serious consequences for humans who have settled in and around these forests.

Low-elevation pine and mixed-conifer forests offer the highest priorities for thinning—in conjunction with prescribed fire—to contribute to restoration of wildlife habitat while making forests more resistant to uncharacteristically severe fire (Miller & Urban 2000). Within these forests, priorities are to reduce surface and ladder fuels and raise the bottom of the live canopy (van Wageningen 1996; Agee et al. 2000). Thinning is most apt to be appropriate where understory trees are sufficiently large or

dense that attempts to kill them with fire would run a high risk of also killing overstory trees (Christensen 1988; Arno et al. 1995; Fulé et al. 1997; Moore et al. 1999; Stephenson 1999). Using prescribed fire alone can be desirable in that it provides the full range of ecological effects of fire. Fire is an imprecise tool, however, whereas individual harvest can provide much more control over which trees are actually killed (Thomas & Agee 1986; Swezy & Agee 1991; Fiedler 1996; Sackett et al. 1996; Pollet & Omi 2002). The larger understory trees that are less likely to be safely thinned with fire are more apt to be large enough to have economic value if they are logged. This presents opportunities to defray expenses and provide employment and wood products, but it also creates economic pressure to cut larger trees. Even where understory trees can safely be thinned with fire, consideration needs to be given to potential smoke production and soil heating during subsequent burns that will be necessary to consume the dead understory trees once they fall to the ground (Agee 1997a; Sackett & Haase 1998).

Within the dry forest zone, high forest integrity will generally be associated with the presence of old-growth trees, especially ponderosa pine (Moir & Dieterich 1988; Wickman 1992; Covington & Moore 1994; Henjum et al. 1994; Brown et al. 1999; Kaufmann et al. 1999). Treatment of these areas could help secure the remnant intact stands from wildfire risks and extend more natural stand conditions across the landscape. Care should be taken, at the landscape scale, to retain some patches of young pine trees in an approximation of historic patterns (Allen et al. 2002).

Mid-seral ponderosa pine stands (roughly 60–100 years old) represent a secondary priority for restoration treatments. These stands are often developing old-growth characteristics but are usually too dense. Treatments to help maintain this trend can increase the probability that old-growth habitats are restored more quickly than they would be otherwise. Variable-density thinning mimics the clumped distribution and associated processes found in pre-1850 stands (Franklin et al. 1997; Harrod et al. 1999). Processes other than fire, particularly sources of mortality such as bark beetles, which are a key food source for woodpeckers and influence the subsequent decay of snags (Samman & Logan 2000; George & Zack 2001), should be provided for at the landscape level.

Reaching some desired future condition in one treatment, in contrast to a staged approach, is being debated (Covington 2000; Fulé et al. 2001, 2002; Allen et al. 2002). The debate is about the efficacy of treatment, how much of a landscape needs to be treated, and how to optimize fuel treatment in relation to other ecological objectives. One option is to rapidly emulate historic structure by retaining trees older than a particular year (1870 in the restoration of Fulé et al. 2001) and removing all others. Another is to combine that treatment with others using only minimal thinning or prescribed fire (Fulé et al. 2002).

Allen et al. (2002) argue that restoration should be aimed at resetting ecosystem trends toward an envelope of "natural variability." They caution that impatience, overreaction to risks of crown fire, extractive economics, or hubris could further damage ecosystems desperately in need of restoration.

Support for their call for caution is provided by data from the Grand Canyon provided by Fulé et al. (2002). They applied three treatments to ponderosa pine forest plus a control: a "full" restoration that removed all trees germinating after 1870 and applied fuel treatment, including prescribed burns; a "minimal" treatment that thinned small trees only around old-growth trees and applied the same fuel treatment as for the full treatment, and a "burn" treatment that used only prescribed fire. The most intrusive full treatment reduced crown-fire hazard the most. However, both the burn and control stands had crowning indices requiring windspeeds well above the 97th percentile wind recorded at the site over many years, and therefore crown fire was not a particularly severe threat. The scorch provided by the prescribed fire in the burn treatment reduced torching potential close to that achieved by the full treatment, so from a fire perspective alone a "full" restoration was not necessary at this site.

Mixed-Severity Fire Regimes

Mid-elevation moist forests of the western United States are more difficult to describe in general terms. Cooler, moister conditions allow less drought- and fire-tolerant species such as grand fir (*Abies grandis* [Dougl.] Lindl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), Douglas-fir, western larch, and ponderosa pine to grow more densely in these areas. In some areas these sites support ponderosa pine-dominated stands that appear similar to the drier forests at lower elevations, although their fire histories may be more complex and variable over long time periods (Shinneman & Baker 1997; Brown et al. 1999; Veblen et al. 2000). Fire-return intervals of 40–80 years included areas burned from low to high severity, a "mixed-severity" fire regime. Fires of differing severity can occur in close proximity, creating a complex mosaic of forest structures in patches of varying size (Taylor & Skinner 1998). Fire suppression has generally been effective for one to four fire cycles and has allowed the development of denser, multistoried forests on more of the landscape. Although the fire regime can still be described as mixed, the relative proportion of fire types has shifted, and severe fires are more likely to occur on more of the landscape than they would have historically (Agee 1998; Agee 2002).

The mixed-severity fire regimes are less clearly candidates for thinning and/or fire restoration. Changes following decades of fire exclusion will often mean that reintroduction of prescribed fire without thinning will be problematic (Agee & Huff 1986). Past management practices

may have led to development of old-growth stands with "unnatural" multiple canopy layers or accumulations of snags and logs, but these areas may provide key habitat that compensates for the loss and degradation of these habitat elements elsewhere (ICBEMP 2000; Wisdom et al. 2000). It may often be appropriate to attempt to secure such habitats from wildfire by treating adjacent areas (Agee 1996, 1998). Attention should be given to protecting large and old trees (Henjum et al. 1994; Allen et al. 2002). Large fir trees, especially those with heartwood decay, provide important habitat for many species (Bull et al. 1992, 1997; Bull & Hohman 1993), and efforts to "cleanse" the landscape of true firs should be avoided. Strategic location of fuel treatments may slow the spread of fire across the landscape (Agee 1999; Finney 2001; Finney et al. 2002b), but this concept has been explored only in computer models and needs refinement before being extensively applied. All in all, these complexities appear to recommend a cautious approach to restoration efforts in mixed-severity fire regimes.

High-Severity Fire Regimes

Wet and cold forests have historic fire-return intervals that typically exceed several centuries. In coastal areas, forests of Sitka spruce (*Picea sitchensis* [Bong.] Carr.) may show evidence of a single fire per millennium (Fahnestock & Agee 1983), whereas widespread western hemlock (*Tsuga heterophylla* [Raf.] Sarg.)–Douglas-fir forests had typical fire-return intervals exceeding 200 years (Agee 1993). At higher elevations, forests of subalpine fir, Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), and lodgepole or whitebark pine (*Pinus albicaulis* Engelm.) predominate. These forests also have long fire-return intervals and contain a high proportion of fire-sensitive trees (Fig. 1). At periods averaging a few hundred years, extreme drought conditions would prime these forests for large, severe fires that would tend to set the forest back to an early successional stage, with a large carry-over of dead trees as a legacy of snags and logs in the regenerating forest. Young forests growing within a matrix of unsalvaged snags and logs may be the most depleted forest habitat type in regional landscapes, particularly at low elevations (Lindenmayer & Franklin 2002).

The fire regime for these forests can be described as "weather-dominated" in that high fuel loads are typical and the fire events that determine forest patterns occur under uncommon, extreme weather conditions that can result in stand-replacing fires over large areas (Agee 1997b). Although logging and road building have had some detrimental effects on these forests, natural ecological dynamics are largely preserved because fire suppression has been effective for less than one natural fire cycle. Thinning for restoration does not appear to be appropriate in these forests (Agee & Huff 1986). Efforts to

manipulate stand structures to reduce fire hazard will not only be of limited effectiveness (Fig. 1; Agee 1996, 1998) but may also move systems away from pre-1850 conditions to the detriment of wildlife and watersheds (Johnson et al. 1995; Weatherspoon 1996). Fuel levels may suggest a high fire "hazard" under conventional assessments, but wildfire risk is typically low in these settings.

Using Place to Set Priorities

Prioritizing restoration efforts is essential because resources are limited. An initial focus on areas most likely to provide benefits and that present a low risk of degradation of ecological values will build experience and credibility. Strategies for conserving both aquatic and terrestrial resources at multiple scales are based on similar principles: secure areas with high ecological integrity ("anchor habitats"), extend these areas, and connect them at the landscape level (Lee et al. 1997; Gresswell 1999). An approach that considers the condition of a watershed and its associated forests and the status of aquatic populations (Rieman et al. 2000) appears to offer the best prospects for balancing potentially competing objectives (Bisson et al. 2003). Restoration treatments should initially focus on uplands (Johnson et al. 1995; Gregory 1997; Lee et al. 1997). Carefully applied prescribed fire may be the most appropriate treatment in riparian areas that historically burned frequently (Kauffman et al. 1997; Agee 1999; Everett et al. 2003).

Although the principles of fire-safe forest can be applied to any forest, they will be most effective when applied to those that are at risk of uncharacteristically severe wildfire and those that are composed of species that develop fire resistance, primarily with thick bark. At least two scales of priority are likely to exist. At a coarse scale, historically low-severity fire regimes will receive highest priority, mixed-severity fire regimes will have moderate priority, and high-severity fire regimes will have low priority. High priority would be assigned, for example, to the ponderosa pine series, the Douglas-fir dry plant association group (PAG), and the grand fir dry PAG. Moderate priority would be assigned to Douglas-fir and grand fir wet PAGs and to the red fir (*Abies magnifica* Murr.) series. Low priority would be assigned to the Sitka spruce series, western hemlock series, Pacific silver fir (*Abies amabilis* [Dougl.] Forbes) series, mountain hemlock series, and subalpine fir series, unless unusual situations exist in which local treatment was needed. A second scale of priority can be defined within the low-severity fire regimes. Some of the more productive forests with a low-severity fire regime in the grand fir, Douglas-fir, and white fir series have experienced more substantial ecological change (Agee 2003) than drier sites in the ponderosa pine and Douglas-fir series. The accumulated biomass in these systems and their abnormally high tree density and wildfire potential argue for a higher priority for restoration within

the low-severity fire regimes. Although treatment costs may be high, these sites also have high potential to offset costs through commercial use of thinned trees.

Conclusions

Action must be taken to reverse trends of ecosystem degradation due to past forest management. Thinning and fire will play a role in these restoration efforts, but both techniques will be controversial. Because thinning is a form of logging and prescribed fire can produce excessive smoke and can escape, these tools need to be strategically applied in ways and locations that will give them the highest prospects for success and the lowest likelihood of unintended consequences. Some areas need no treatment at all. Other areas needing treatment will have to be triaged because of limited resources. Based on current knowledge (adapted from Brown 2000; Allen et al. 2002), it appears that the most credible restoration efforts will

- place highest priority on historically low-severity fire regimes, with secondary priority on mixed-severity fire regimes, and lowest priority on high-severity fire regimes;
- be based on the ecology of the species and site, with presettlement conditions as a sustainable reference, recognizing different goals for a wide variety of landowners;
- be site-specific and consider the landscape context, including watershed conditions and fish and wildlife habitat;
- consider a range of restoration steps, rather than attempt complete restoration with a single treatment everywhere;
- maintain the most fire-resistant, large-tree component of the forest in active-management schemes;
- consider mechanical thinning and prescribed fire as acceptable tools, but in all cases apply fire-safe principles (Table 1);
- where thinning is used, apply minimal-impact harvesting techniques, and focus first on areas where road systems are largely complete; and
- make a commitment to long-term monitoring and adaptive management so that we learn by doing.

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